STRESS - STRAIN DIAGRAMS IN THE PLASTIC RANGE

A THESIS

Presented to

the Faculty of the Graduate Division

by

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STRESS- STRAIN DIAGRAMS

IN THE

PLASTIC RANGE

APPROVED

DATE APPROVED BY CHAIRMAN Aug. 21, 1959

ACKNOWLEDGMENTS

Upon arriving at the end of this thesis, I would like to express deep thanks to Dr. J. P. Vidosic for the suggestion of this problem and for his continual assistance. Thanks also go to Dr. H. S. Weber and Prof. F. M. Hill for their helpful suggestions. I wish to express gratitude to the Georgia Tech Photo Lab and Marshall Cooksey for the use of their equipment and photographic knowledge. A special thanks goes to Mr. G. L. Brinkworth of the Aluminum Company of America who was extremely kind and helpful to me. Finally I would like to express deepest thanks to my parents, Mr. and Mrs. E. C. Brisbane, who made this thesis possible by their encouragement, help, and self sacrifice.

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GLOSSARY OF ABBREVIATIONS

S True stress.

ϵ True strain.

ϵ_f True strain at fracture.

P The load in pounds that is applied to the specimen.

A The cross sectional area of the specimen.

m When used as a subscript, it means the value of the subscripted variable at the point of maximum load.

V Volume.

SUMMARY

The results of the normal tension test in which the strain is measured over a two inch gage length and the stress is determined by using the original cross sectional area are limited in their usefullness. In processes such as cold working, spinning, and forming which take place in the plastic region, the knowledge of a true stress strain diagram is necessary.

A new method known as the photo-grid technique is used to obtain experimental data in the plastic region for true stress strain diagrams. This method uses a one quarter inch gage length and the instantaneous area to determine the stress and strain at desired loads.

Fifteen types of engineering materials were tested in this investigation. There were six steels, six aluminums, two nickels, and one brass included in the fifteen materials. Three round ASTM standard tension test specimens of each material were tested.

The use of the data in the plastic range can be simplified if formulas covering this region could be established. It is pointed out that work has been done in trying to develop theoretical formulas that would fit experimental data in the plastic range. However, none of the theoretical formulas pointed out fit the straight line portion of the curve that occurs after the maximum load has been reached.

After the experimental data had been obtained and investigated, it was decided that it would be best to use two simple formulas to fit the experimental data in the plastic range. The formula of J. H. Hollomon gave a good fit up to the maximum load. A new approximation

was required in the region from maximum load to fracture.

The new approximations were found by using the theory of least squares. In order to speed up the computations, a program was written for the IBM 650 digital computer.

The empirical formulas established for the region past the maximum load are straight lines with two exceptions. The two exceptions are very close to being straight lines but are best fitted with exponential curves. The fact that the straight lines occurred is an indication of the reliability of the data, for this agrees with statements brought out in the review of literature.

A recommendation is made this method of testing be tried on specimens where the attaching of an extensometer is not permissible.

CHAPTER I

INTRODUCTION

Definition of the problem. -- The tension test has rapidly become the leading method for determining the properties of a metal. The conventional tension test in which results are determined by using the load divided by the original area for the stress and the change in gage length divided by the original gage length for the strain has been found inadequate for determining properties in operations which are outside the elastic range. In order to correlate the stresses and strains determined in a tension test with those present in metal forming operations, cold working processes, and other operations which are not static, a knowledge of the true stress strain relation must be obtained.

To facilitate the use of the experimentally determined data, there have been attempts to approximate curves to the data. The majority of these approximations have formerly been made theoretically. The approximations made in this thesis will be determined experimentally by the process of least squares.

The method of testing used is a new one known as the photo-grid technique developed by T. G. Stastny (1)*. This method defines stress as the load divided by the instantaneous area and the strain as the change in gage length divided by the original gage length. A small gage length of one-quarter of an inch is used in order that the true strain may be approached.

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* Numbers in parentheses refer to items in the bibliography.

Review of the literature. -- MacGregor (2) in his discussion of the tension test states the stress strain conditions based on the original conditions exist only in the very early stages of testing. MacGregor also separates the true stress strain curve into four regions which are: (1) The so-called elastic region; (2) The yield point elongation portion; (3) The region from the yield point elongation end to the point of maximum load; and (4) The necking region in which the load drops until fracture.

The approximations of J. H. Palm (3), J. H. Hollomon (4), and Ludwik (5) attempt to cover the last three regions stated above or from the yield point until fracture. This range is normally referred to as the plastic region.

Ludwik proposed that the approximation be of the form:

$$S = K_1 + K_2\epsilon^{K_3}$$

where K_1 , K_2, and K_3 are constants. The use of the exponential curve was also proposed by Hollomon (4) in the shorter form:

$$S = K_1\epsilon^{K_2}$$

Where K_1 and K_2 are constants but have no connection with the constants of Ludwik's formula. This formula and its constants will be discussed further in the following chapter.

J. H. Palm states that the empirical formulas of Ludwik and Hollomon cannot agree with the behavior of the metal in the range from maximum load to fracture and gives his own approximation.

This formula is:

$$S = S_t - (S_t - S_e)e^{-\epsilon/\epsilon_c}$$

In his article Palm illustrates how to find the constants S_t, S_e, and ϵ_c. This curve fails to agree in the region after the maximum load as well as Holloman's approximation but gives better agreement up to the maximum load.

All three of these men along with MacGregor state the true stress strain curve is approximately a straight line in the region from maximum load to the fracture. MacGregor (6) gives a quick method for finding this straight line portion of the curve called the two-load method. In this method the stress strain readings are taken only at the maximum load and at the fracture of the specimen.

The above approximations will be used to determine the type of approximations to be made in this investigation.

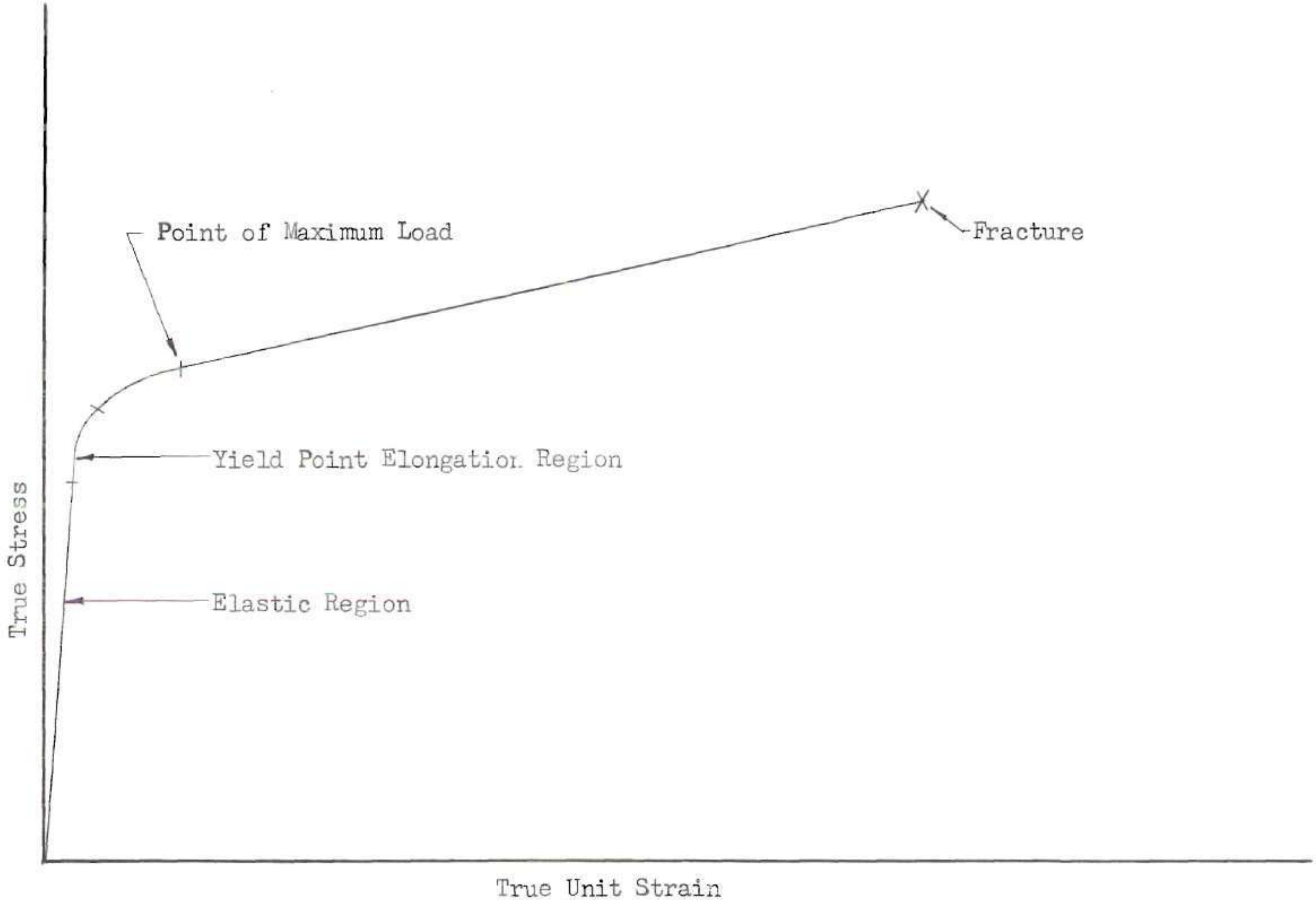


Figure 1. Typical True Stress- Strain Diagram

CHAPTER II

HOLLOMON'S APPROXIMATION (4)

Hollomon's short form of the exponential approximation has been in wide use in the United States and therefore is further discussed here. Hollomon presents a theoretical derivation to show how to find the constants in his equation.

$$S = K_1 \epsilon^{K_2} \tag{1}$$

$$\frac{dS}{d\epsilon} = K_1 K_2 \epsilon^{(K_2 - 1)} = \frac{S K_2}{\epsilon}$$

at maximum load

$$\left(\frac{dS}{d\epsilon}\right)_m = \frac{S_m K_2}{\epsilon_m} \tag{2}$$

Now using $P = SA$

$$dP = AdS + SdA$$

or at maximum load

$$0 = (AdS + SdA)_m$$

$$(AdS)_m = -(SdA)_m$$

$$\left(dS \Big/ \frac{-dA}{A}\right)_m = S_m$$

Now applying the theory that the volume remains constant throughout the test will give the following:

$$V = A \times L = K(\text{Constant})$$

$$LdA + AdL = 0$$

$$\frac{dL}{L} = -\frac{dA}{A} = d\epsilon$$

Using this relationship for strain gives

$$\left(\frac{dS}{d\epsilon}\right)_m = S_m \qquad (3)$$

Referring to relations (2) and (3)

$$\frac{K_2}{\epsilon_m} = 1 \quad \text{or } K_2 = \epsilon_m$$

Therefore formula (1) can now be written

$$S = K_1 \epsilon^{\epsilon_m} \qquad (4)$$

At maximum load from (4)

$$K_1 = \frac{S_m}{(\epsilon_m)^{\epsilon_m}}$$

Substituting this for K_1 in (4) gives

$$\frac{S}{S_m} = \left(\frac{\epsilon}{\epsilon_m}\right)^{\epsilon_m} \qquad (5)$$

This final formula was found by Hollomon to give a curve that agreed with experimental data only to a very approximate degree in the region after maximum load, but it was better than the other approximation. It was observed that better results could be obtained by changing the values of the constants, but then the formulas had no theoretical significance. As the formula stands, the approximation can be obtained by knowing the value of the stress and strain at the maximum load, which is very convenient

CHAPTER III

EQUIPMENT

Test specimens. -- Fifteen types of materials were used. They were selected to give a wide variety of strengths and alloying materials and also because they are typical engineering materials. The materials are:

STEEL	ALUMINUM
SAE 1012	AA - 2024-O
SAE 1020	AA - 3003-O
SAE 1042	AA - 3004-O
SAE 1095	AA - 5052-O
SAE 8620	AA - 6061-O
Max-el 1B by Crucible Steel	AA - 7075-O
Yellow Brass	NICKEL
	MONEL-R
	INCONEL

The test specimens were made according to American Society for Testing Metals (7) standards. The specimens were round with a 3/4 inch nominal diameter and a nominal 0.505 inch diameter test section $2\frac{1}{4}$ inches long which was smoothly turned.

Grid negative and chemicals. -- The grid negative which was used was one which was developed by the U.S.Bureau of Standards for measuring small gage lengths. The vertical and horizontal lines are 0.006 inch thick and 0.01 inch apart covering an area of 2.07 inches by 2.16 inches.

A copy of this negative had been previously obtained from Lockheed Aircraft Corporation, and several more copies were made for use in the test.

Freuendorfer Cold Top Enamel and Developer by Philip Lochman Company were used to develop the grid on to the specimen. A 95 per cent grade A alcohol was used to thoroughly clean each specimen before the grid was applied.

A 100 watt AH-4 mercury arc lamp was used to expose the enamel on the specimen. A shiny reflector was used to reflect the light from behind the specimen in order that the specimen sides also be exposed.

Testing Machines. -- Two testing machines were used because of the wide range of tensile strengths. The aluminum and brass specimens were tested on a Tinius-Olsen Plastiversal. Steel and nickel specimens were tested on a Riehle tension test machine. Both of these machines are screw operated affording good test control.

The Plastiversal machine provides three scales including 0-500 lbs., 0-10,000 lbs. and 0-20,000 lbs.; the Riehle machine provides five scales including 0-22,500 lbs., 0-45,000 lbs., 0-90,000 lbs., 0-225,000 lbs., and 0-450,000 lbs. Both machines had been recently calibrated and errors found to be negligible.

Photographic equipment. -- In order to obtain the high resolution necessary to photograph the fine lines a short focal length camera was needed. A Graflex Photo-Record camera was used along with high resolution, 35mm. microfile film.

Two 150 watt photo spots were used to illuminate the specimen, and a small reflector of dull aluminum was placed behind the specimen to even out the light and to give a clear outline of the specimen.

When the Riehle machine was used, a Majestic tripod was used to hold the camera. However, the camera could be brought closer to the specimen by use of a specially made boom on the Tinius-Olsen machine. This boom and its set-up can be seen in figure two.

Reading the films. — A microscopic film reader with a micrometering attachment was used for reading the strains of the specimens as well as the diameters.

CHAPTER IV

PROCEDURE

Applying the grid. -- A small amount of enamel was poured into a small tray while enough developer and alcohol to cover about half of the specimen were poured into two $8\frac{1}{2}$ x 11 inch trays. The specimen was first cleaned very thoroughly with the grade A alcohol. Care was taken to make sure all of the grease had been removed so that the enamel could adhere to the surface of the specimen.

The enamel was applied to the specimen with a No. 6 sable brush using smooth even strokes . Additional strokes were sometimes necessary to thin out the coat or to remove air bubbles. The specimen was then dried by an electric hair dryer.

When the specimen was dry, the grid negative was wrapped tightly around it and clamped at the back. Care was taken to make sure that there was emulsion to emulsion contact and that the fit was tight. The specimen was then exposed by standing it on end for about ten minutes at five inches distance from the 100 watt AH-4 mercury arc lamp. Exposing the specimen for a lesser time caused the grid to wash off in the developer.

After the exposure was finished the grid negative was removed and the specimen was carefully rolled in the developer for about twenty seconds. Then the specimen was put in the alcohol where it was slowly agitated to remove the excess developer. This was followed by a dip into a pan of water which was kept clear by changing it as soon as it became discolored. The final dipping removed the alcohol which becomes discolored due to the developer. If the alcohol was not removed the specimen sometimes had a cloudy look. Following the water bath the specimen was again dried with the hair dryer.

If the specimen is of steel and is not going to be used soon the water bath should be eliminated because otherwise rust will be formed.

Photographing the specimen. -- The specimen was placed in the jaws very firmly so that it would not fly out and hit the camera upon fracturing. The reflector was placed behind the specimen once it was secured in the jaws.

The mounting of the camera differed according to which testing machine was being used. It was desired that the lens of the camera be about twelve inches from the specimen for this gives a picture of good readable size. This requirement could be met when the specially constructed boom was used on a Tinius-Olsen machine. The boom was not adapted to the Riehle machine, and a tripod was used which places the lens about twenty inches from the specimen. This resulted in smaller pictures which were harder to read. In each case, the camera must be firmly mounted so that it does not vibrate or the pictures will not be clear.

Focusing the camera is a very delicate job, but it was made easier by a ground glass attachment on the camera. A Bausch and Lomb hand microscope was focused on the etchings of the glass, and the camera was then focused by the slow motion focusing knob until the grid could be seen in the microscope. Once the focusing was complete the ground glass attachment was removed and the film magazine was attached. The lens opening was set at f8 and the shutter speed at 1/25.

The two 150 watt reflector spot lamps were directed onto the specimen at a 45 degree angle from the line of photography. These lamps were placed about thirty inches from the specimen on each side of the camera and are connected to a common on-off switch.

Each specimen was individually focused at the start of each test. The first picture of each test was used for identification. A small white card with identifying remarks was held in front of the specimen for this purpose. The second picture was always taken at zero load. With the machine pulling at a constant strain rate of 0.05 inches per minute for the steel, nickel, and brass and at 0.025 inches per minute for the aluminum, several pictures were taken on the way up to maximum load. A larger number of photographs was taken past the ultimate load which was the region of most interest. The two spot lamps were turned off after each picture to prevent heating the specimen and film was advanced in the magazine. Approximately twenty pictures were taken in each test.

Determination of stress and strain. — The film was analyzed on a microscopic micrometering film reader which had a micrometer screw. This screw advanced the microscope which was focused on the film. The micrometer had a vernier which allowed the reading of distances of 0.001 millimeters. The strain was determined by reading the distance between twenty-five lines which were centered in the neck-down region of the specimen.

The actual initial diameter of the specimen was determined by a micrometer. Several readings of the initial diameter of the specimen on the film were taken, and the average of these was used to determine a factor that permitted the finding of the area from the specimen diameter on the film. This factor was only applied to the diameter, for the unit strain itself is dimensionless.

Approximations to the experimental points. -- The approximations were made by a least squares process as described in Scarborough (8) and Milne (9). In order to ease the work of computation a program was written for the IBM 650 digital computer. This program can be found in appendix A.

The type approximation to be used was found by plotting the points on rectilinear graph paper, semi-log graph paper, and log log graph paper until a straight line was obtained.

CHAPTER V

DISCUSSION OF RESULTS

Three specimens of each of fifteen materials were tested. The individual graphs of true stress against true strain can be found in the appendix. The results obtained were consistent and differed in the three specimens only slightly as might be expected.

It was found impractical to obtain a simple expression for a curve that covers the entire plastic region. It was also observed earlier the approximations of J. H. Palm, and J. H. Hollomon were good only up to the point of maximum load. Thus, it was decided approximations of this investigation would be for the range from maximum load to fracture.

Experimental points were plotted, and in all but two cases the graph from maximum load to fracture was a straight line. The two exceptions were 8620 steel and 1042 steel. These two materials were found to need an exponential curve, for the points fell in a straight line when they were plotted on semi-log graph paper.

A least squares program was written for the IBM 650 digital computer. This program can be found in appendix A. All points for each single material were plotted along with the point approximations. These curves can be found in appendix B along with the individual curves.

The resulting approximations along with the limits of the independent variable follow this discussion. The limits were found by averaging the strains of the three specimens at maximum load and at fracture. The stress at maximum load is also given so that Hollomon's approximation can be used in the region from the yield point up to the maximum load.

The data for one specimen of each type material is included in appendix C as typical data.

Table 1. Stress-Strain Relations From Least Squares Process

Material	Specimen No.	Condition	Least Squares Approximations	ϵ_f	ϵ_m	S_m
1012 Steel	7,8,& 9	As Rolled	$S = 58{,}166 + 50{,}695\epsilon$	1.1228	0.2695	72,643
1020 Steel	4,5,& 6	As Rolled	$S = 69{,}555 + 56{,}470\epsilon$	0.9343	0.2220	80,642
1042 Steel	10,11,& 12	As Rolled	$S = 94{,}427\ e^{0.61162\epsilon}$	0.5372	0.1822	106,390
1095 Steel	14,& 15	As Rolled	$S = 144{,}647 + 68{,}872\epsilon$	0.1374	0.1022	151,170
8620 Steel	20,21,& 22	Cold Drawn	$S = 105{,}073\ e^{0.52358\epsilon}$	0.5765	0.0320	108,170
Crucible 1B	17,18,& 19	As Rolled	$S = 66{,}251 + 63{,}406\epsilon$	0.9730	0.2112	83,928
Al 2024-0	42,43,& 44	Annealed	$S = 32{,}551 + 27{,}766\epsilon$	0.6470	0.1275	36,088
Al 3003-0	32,33,& 34	Annealed	$S = 15{,}172 + 12{,}378\epsilon$	0.9897	0.2078	18,347
Al 3004-0	48,49,& 50	Annealed	$S = 30{,}269 + 28{,}160\epsilon$	0.7112	0.1922	35,430
Al 5052-0	45,46,& 47	Annealed	$S = 29{,}376 + 28{,}769\epsilon$	0.8907	0.2486	36,407
Al 6061-0	36,37,& 38	Annealed	$S = 17{,}867 + 15{,}570\epsilon$	1.0284	0.1994	20,942
Al 7075-0	39,40,& 41	Annealed	$S = 33{,}949 + 31{,}227\epsilon$	0.4704	0.1723	38,776
Yellow Brass	1,2,& 3	Annealed	$S = 65{,}227 + 63{,}385\epsilon$	0.5013	0.0669	72,640
Inconel	23 & 27	Annealed	$S = 89{,}075 + 70{,}324\epsilon$	1.1021	0.4299	122,320
Monel-R	24,25,& 26	As Rolled	$S = 90{,}648 + 74{,}580\epsilon$	0.8561	0.0879	97,800

CHAPTER VI

CONCLUSIONS

Formulas proposed by J. H. Hollomon and J. H. Palm do not agree with the experimental data in the region following the maximum load. Investigation led to the belief that there is no one simple formula that will fit the entire plastic region. The use of two curves gives better results. Hollomon's formula is sufficient in the region up to maximum load.

The approximations of this investigation do not hold the theoretical significance of the formulas of Hollomon and Palm. However, these empirical relations do give a good fit to the experimental data.

The reliability of the empirical relations obtained in this investigation is attested to by two main facts. First MacGregor, Palm, and Hollomon claimed a straight line for the region from maximum load to fracture. In all but two cases this investigation yielded straight lines; these two cases were nearly straight lines. Second is that the data repeated itself with only the deviations that are expected in materials.

Due to the small strains and the difficulty in measuring them, this method does not give extremely good results in the elastic region. However, the plastic range data is good.

CHAPTER VII

RECOMMENDATIONS

If at all possible, the camera lens should be about twelve inches from the specimen. The photographs taken while using the Riehle tension machine were much harder to read because the specimen appeared smaller. The lens of the camera was about twenty inches from the specimen in this case.

This method of testing is not too satisfactory for some materials. If the material possesses a surface phenomena that causes scaling when the deformation occurs the grid is unreadable. This occurred to a slight degree with the Inconel, and there were only two readable films obtained from five specimens.

The recommendation is made that this method of testing be tried in cases where small articles are being tested and the attachment of an extensometer is not permitted. The grid would not affect the article; whereas a grid of scratch marks, a method sometimes used, would reduce the strength of a small specimen.

A P P E N D I C E S

APPENDIX A

DEVELOPMENT OF LEAST SQUARES PROGRAM

For a set of points (ϵ_i, S_i) where $i = 1, 2, 3, \ldots n$, Milne gives a numerical method for fitting the points with linear approximations by the method of least squares.

If the points are to be fitted with a straight line, the following method can be used. Let the resulting formula be:

$$S = a_1 + a_2\epsilon$$

$$a_1 = \frac{S_2V_0 - S_1V_1}{S_0S_2 - S_1^2} \qquad a_2 = \frac{S_0V_1 - S_1V_0}{S_0S_2 - S_1^2}$$

where

$$S_0 = \sum_{i=0}^{n} \epsilon_i^0 \qquad V_0 = \sum_{i=0}^{n} S_i$$

$$S_1 = \sum_{i=0}^{n} \epsilon_i \qquad V_1 = \sum_{i=0}^{n} S_i\epsilon_i$$

$$S_2 = \sum_{i=0}^{n} \epsilon_i^2$$

If an exponential formula of the form

$$S = a_1e^{a_2\epsilon}$$

is to be used, a transformation to the linear form is first made.

$$\ln S = \ln a_1 + a_2\epsilon$$

Let $S^* = \ln S$ and $A = \ln a_1$

This gives: $S^* = A + a_2\epsilon$

Thus, the same method can be used as for the straight line.

PROGRAM ORDERS FOR IBM 650 COMPUTER IN BELL GENERAL PURPOSE SYSTEM

01	+9	8 0 0	0 0 1	0 0 0	pp. no. 1
02	+9	1 0 0	1 1 1	0 0 0	Step A, B, and C by 1
03	+2	4 0 0	4 0 0	3 0 0	300: ϵ
04	+9	1 0 0	1 1 1	0 0 0	Step A, B, and C by 1
05	+2	4 0 0	5 0 0	2 0 0	200: S
06	+8	1 0 1	0 0 N	0 0 1	Return to pp. 1 N times
07	+9	8 0 0	0 0 2	0 0 0	pp. no. 2
08	+9	2 0 0	0 1 0	0 0 0	Step B by 1
09	+1	3 9 9	4 0 0	3 9 9	399: $\sum \epsilon_i = S_1$
10	+9	2 0 0	0 1 0	0 0 0	Step B by 1
11	+1	2 9 9	3 0 0	2 9 9	299: $\sum \epsilon_i^2 = S_2$
12	+9	2 0 0	0 1 0	0 0 0	Step B by 1
13	+1	4 9 9	5 0 0	4 9 9	499: $\sum S_i = V_0$
14	+9	2 0 0	0 1 0	0 0 0	Step B by 1
15	+1	1 9 9	2 0 0	1 9 9	199: $\sum S_i \epsilon_i = V_1$
16	+8	2 0 1	0 0 N	0 0 2	Return to P.P. 2 N times
17	+2	4 9 9	2 9 9	5 0 0	500: S_2V_0
18	+2	1 9 9	3 9 9	5 0 1	501: S_1V_1
19	-1	5 0 0	5 0 1	5 0 2	502: $S_2V_0 - S_1V_1$
20	+2	1 9 8	2 9 9	5 0 3	503: S_0S_2
21	+2	3 9 9	3 9 9	0 0 0	PR. S_1^2
22	-1	5 0 3	0 0 0	5 0 4	504: $S_0S_2 - S_1^2$
23	+3	5 0 2	5 0 4	6 0 0	600: Compute a_1
24	+2	1 9 8	1 9 9	5 0 5	505: S_0V_1

25	+2	399	499	506	506: $S_1 V_0$
26	-1	505	506	000	PR: $S_0 V_1 - S_1 V_0$
27	+3	000	504	601	601: Compute a_2
28	+7	300	600	601	Punch a_1 and a_2
29	+0	000	000	000	Stop.

STORAGE OF CONSTANTS AND DATA

30 1982 + Store the number N

31 +0 000 000 050

32 2991 + 0 000 000 050

33 3996 + 0 000 000 050

Store ϵ_1 through ϵ_n starting with 400

4996 + 0 000 000 050

Store S_1 through S_n starting with 500

0000 START

To use this same program for the exponential form of the approximation, these supplementary cards are needed.

031	+9	100	011	000	Step B and C by 1
032	+0	302	500	500	500: $\ln S = S^*$
231	+1	301	600	601	601: $a_1 = e^A$
27	+3	000	504	602	602: Compute a_2
28	+7	300	601	602	Punch 601 and 602

Assemble program with 031 and 032 behind card 03. Card 231 goes behind card 23. Cards 27 and 28 replace 27 and 28 of the straight line program.

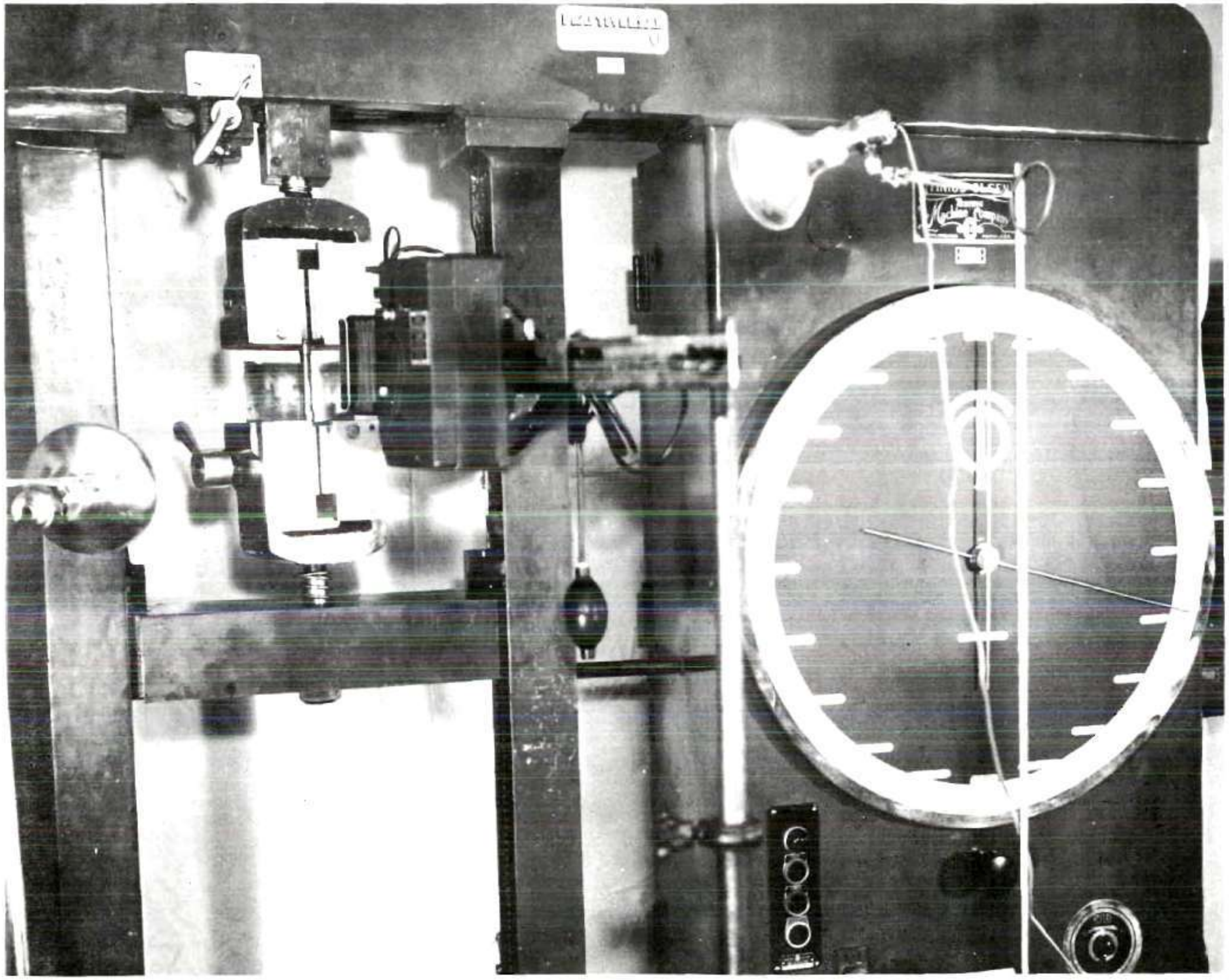


Figure 2. Test Apparatus.

APPENDIX B

Included in this appendix are the bulk of the curves. The individual curves of stress vs. strain for each specimen are found here. Also included are the plots of the approximations to the experimental points.

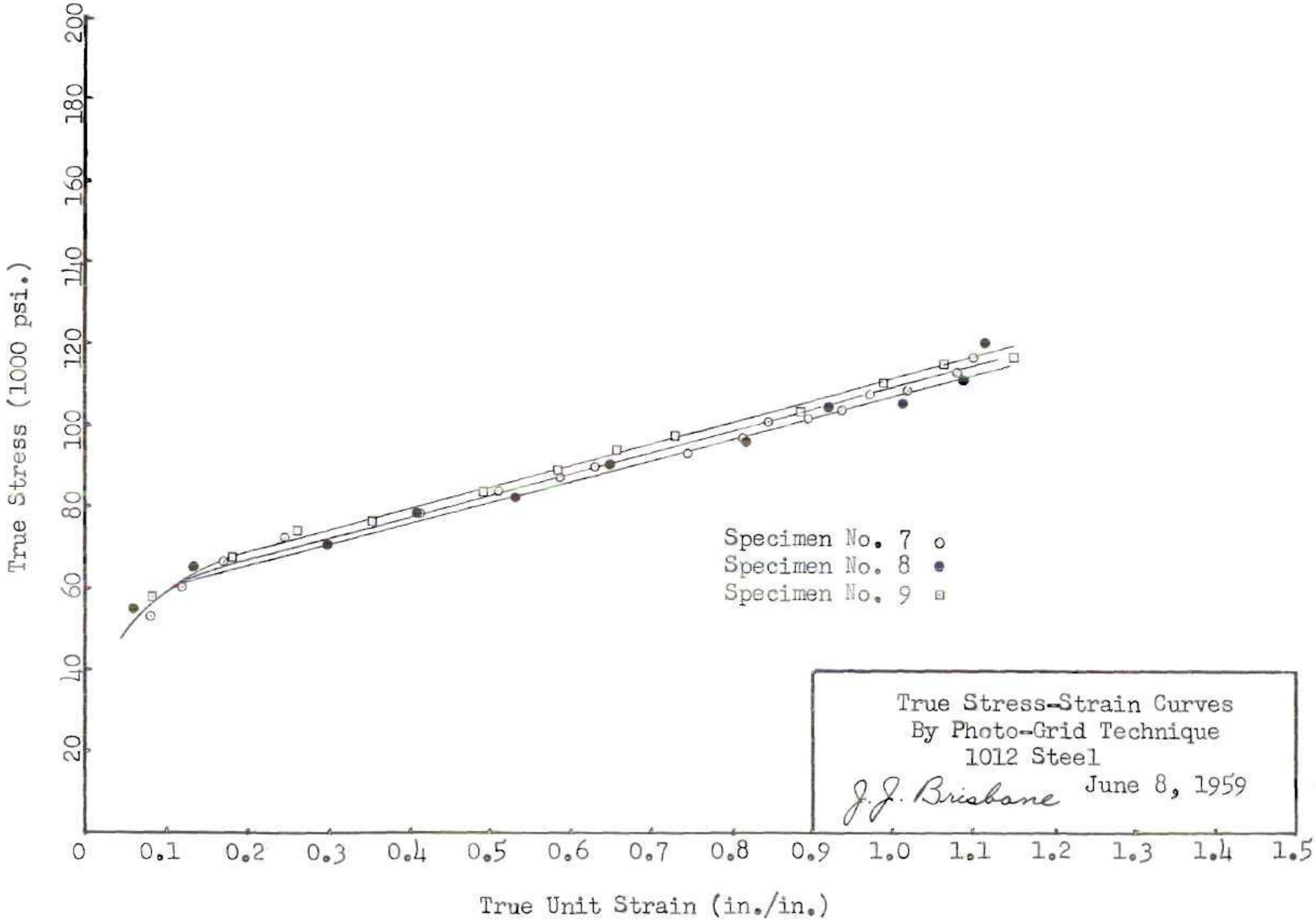
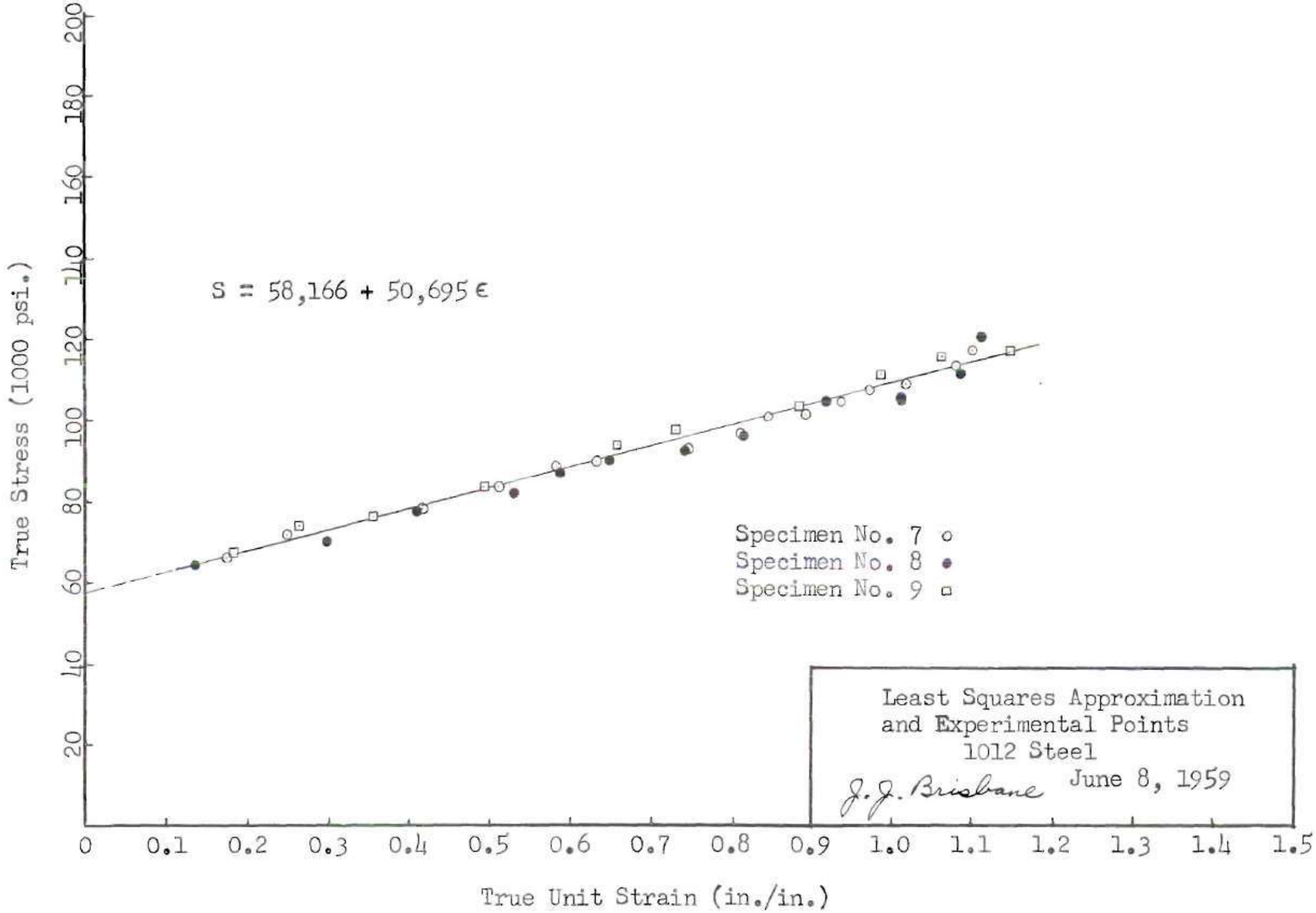

True Stress (1000 psi.)
True Unit Strain (in./in.)
Specimen No. 7 o
Specimen No. 8 ●
Specimen No. 9 □
True Stress-Strain Curves
By Photo-Grid Technique
1012 Steel
J. J. Brisbane June 8, 1959

Figure 3



S = 58,166 + 50,695 ε
True Stress (1000 psi.)
200
180
160
140
120
100
80
60
40
20
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
Specimen No. 7 ○
Specimen No. 8 ●
Specimen No. 9 □
Least Squares Approximation
and Experimental Points
1012 Steel
J. J. Brisbane June 8, 1959
True Unit Strain (in./in.)

Figure 4

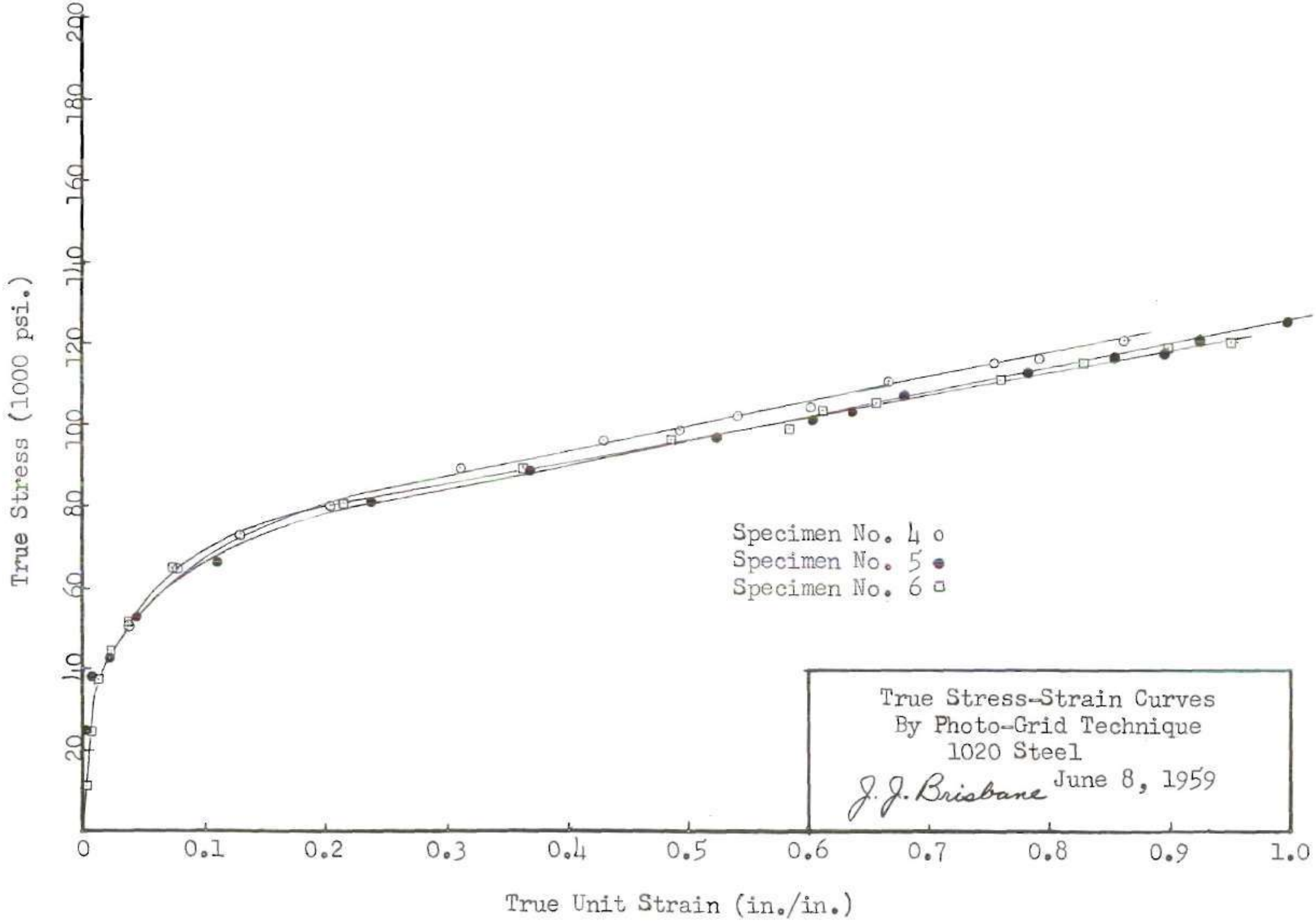

True Stress (1000 psi.)
200
180
160
140
120
100
80
60
40
20
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
True Unit Strain (in./in.)
Specimen No. 4 o
Specimen No. 5 ●
Specimen No. 6 □
True Stress-Strain Curves
By Photo-Grid Technique
1020 Steel
J. J. Brisbane June 8, 1959

Figure 5

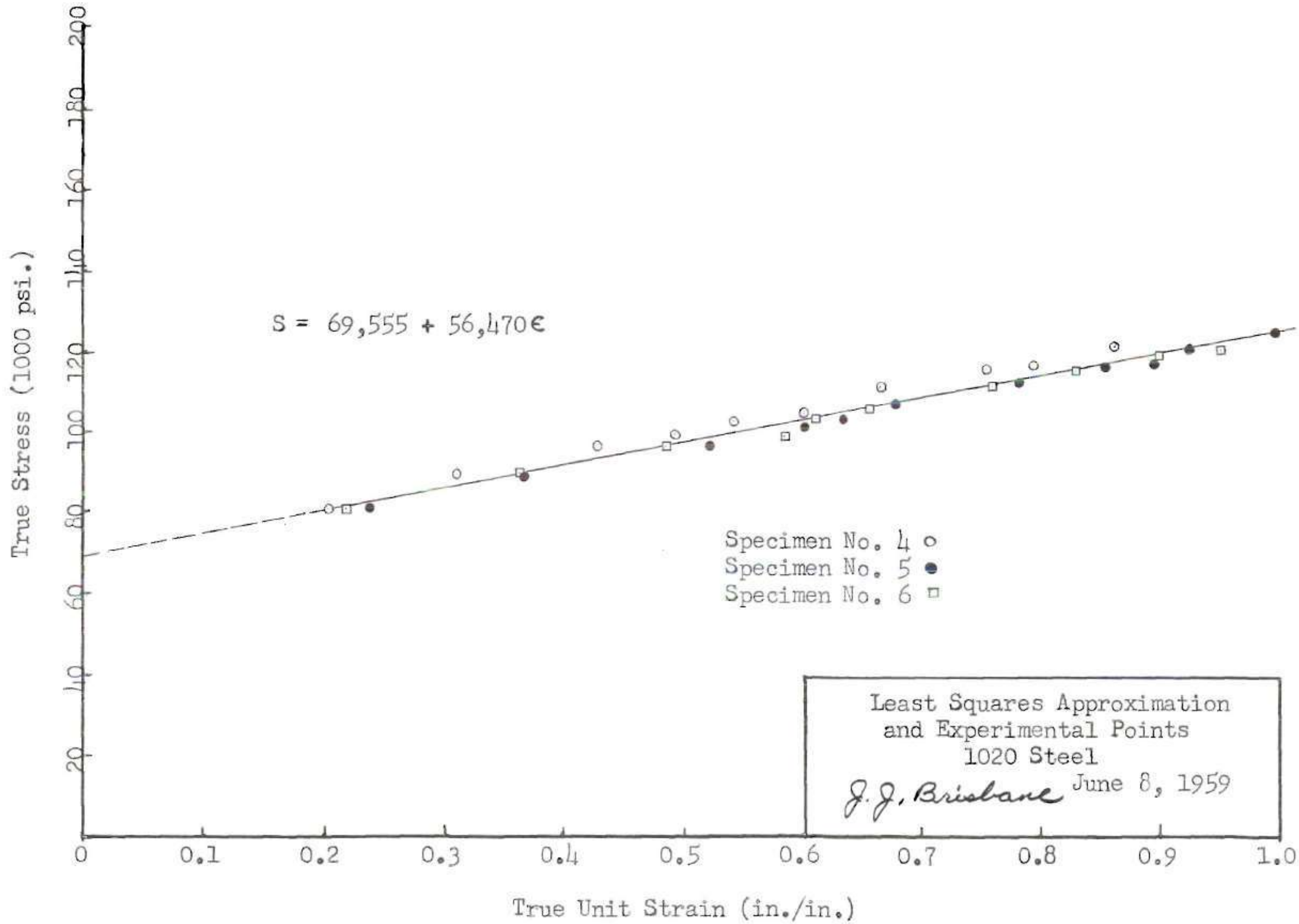
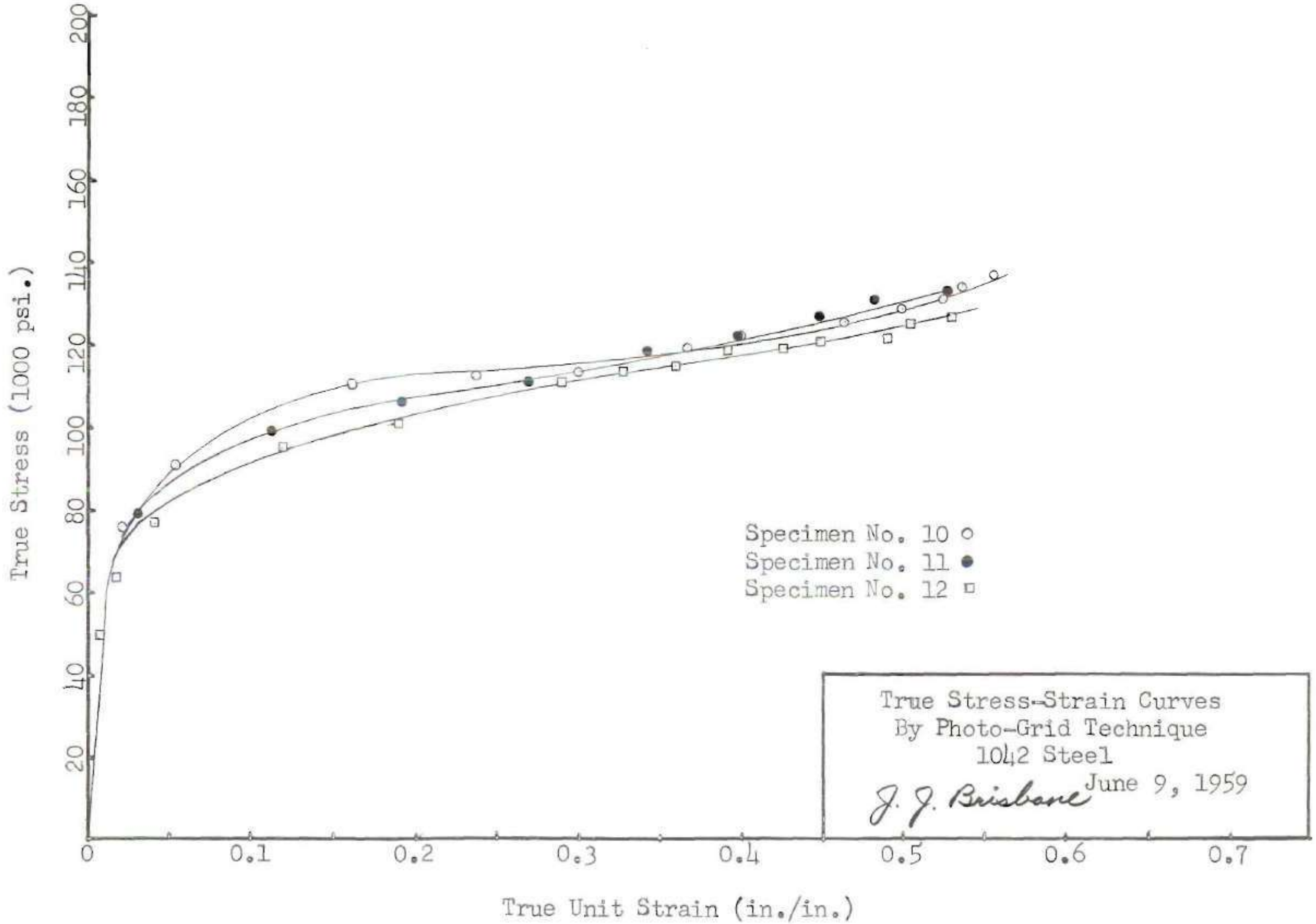

True Stress (1000 psi.)
200
180
160
140
120
100
80
60
40
20
S = 69,555 + 56,470ε
Specimen No. 4
Specimen No. 5
Specimen No. 6
Least Squares Approximation
and Experimental Points
1020 Steel
J. J. Brisbane June 8, 1959
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
True Unit Strain (in./in.)

Figure 6



True Stress (1000 psi.)
200
180
160
140
120
100
80
60
40
20
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
True Unit Strain (in./in.)
Specimen No. 10
Specimen No. 11
Specimen No. 12
True Stress-Strain Curves
By Photo-Grid Technique
1042 Steel
J. J. Brisbane June 9, 1959

Figure 7

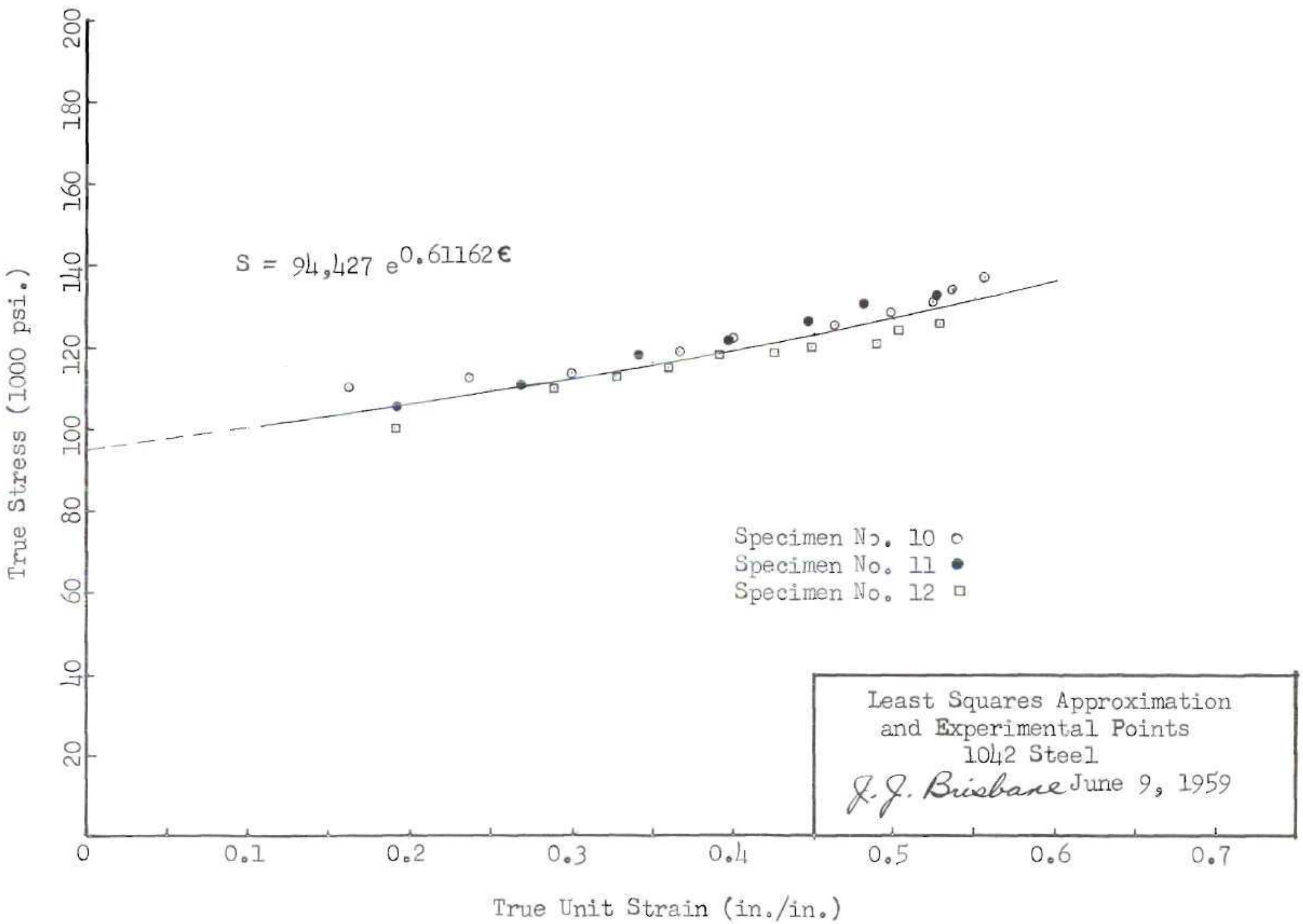
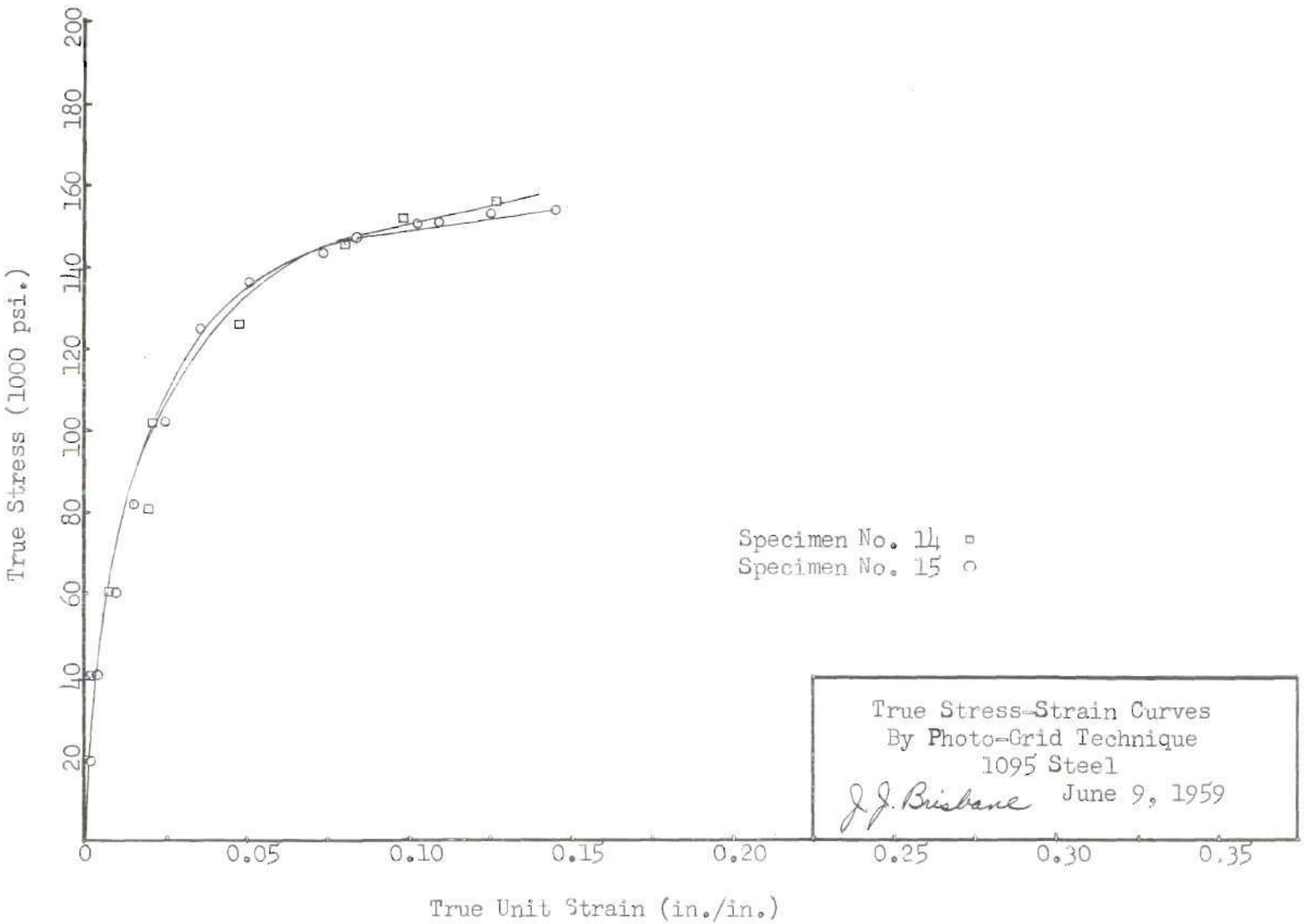

S = 94,427 e^0.61162ε
True Stress (1000 psi.)
200
180
160
140
120
100
80
60
40
20
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
True Unit Strain (in./in.)
Specimen No. 10
Specimen No. 11
Specimen No. 12
Least Squares Approximation
and Experimental Points
1042 Steel
J. J. Brisbane June 9, 1959

Figure 8



True Stress (1000 psi.)
200
180
160
140
120
100
80
60
40
20
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
True Unit Strain (in./in.)
Specimen No. 14 □
Specimen No. 15 ○
True Stress-Strain Curves
By Photo-Grid Technique
1095 Steel
J. J. Brisbane June 9, 1959

Figure 9

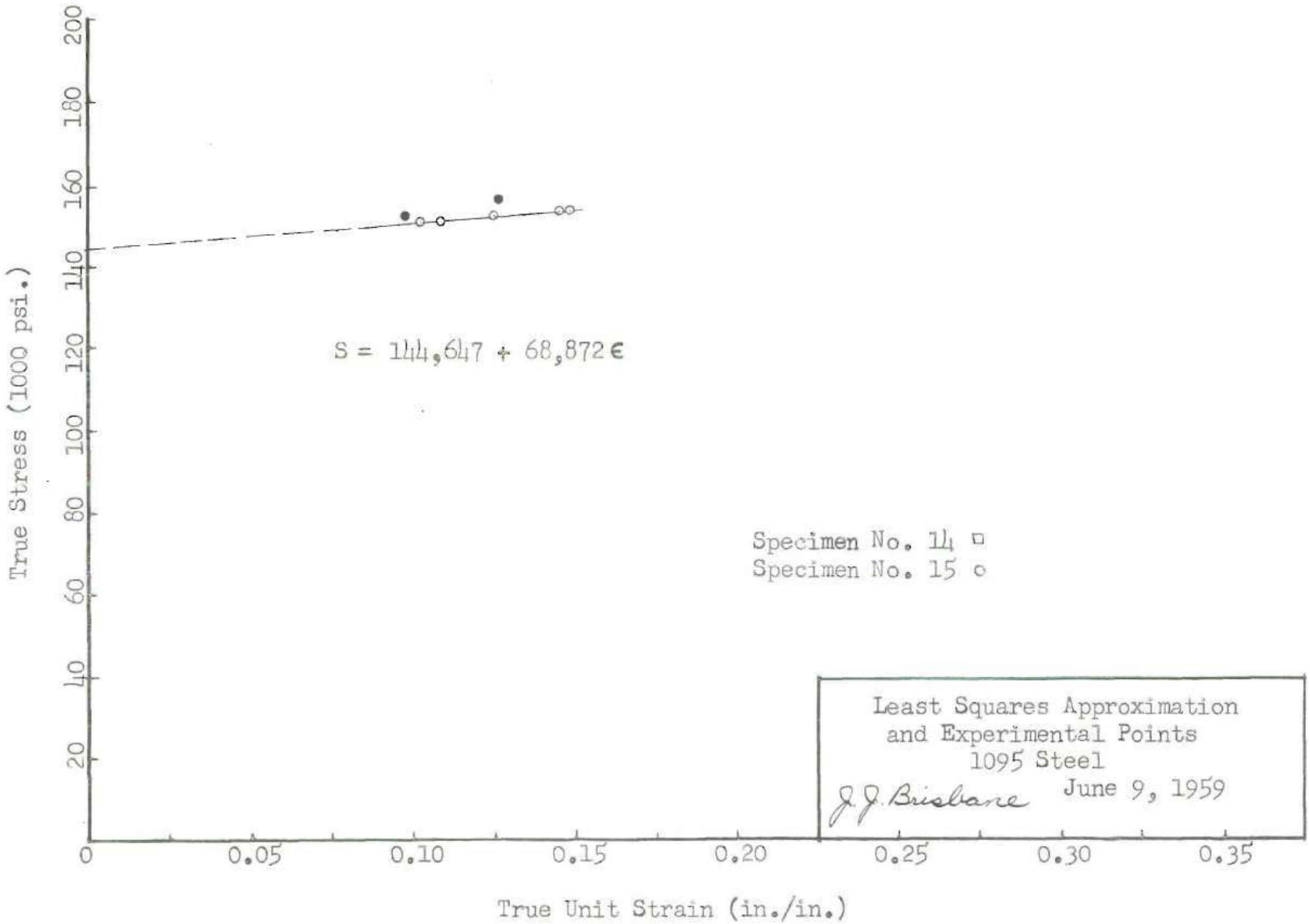

True Stress (1000 psi.)
200
180
160
140
120
100
80
60
40
20
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
True Unit Strain (in./in.)
S = 144,647 + 68,872 ε
Specimen No. 14 □
Specimen No. 15 ○
Least Squares Approximation
and Experimental Points
1095 Steel
J. J. Brisbane
June 9, 1959

Figure 10

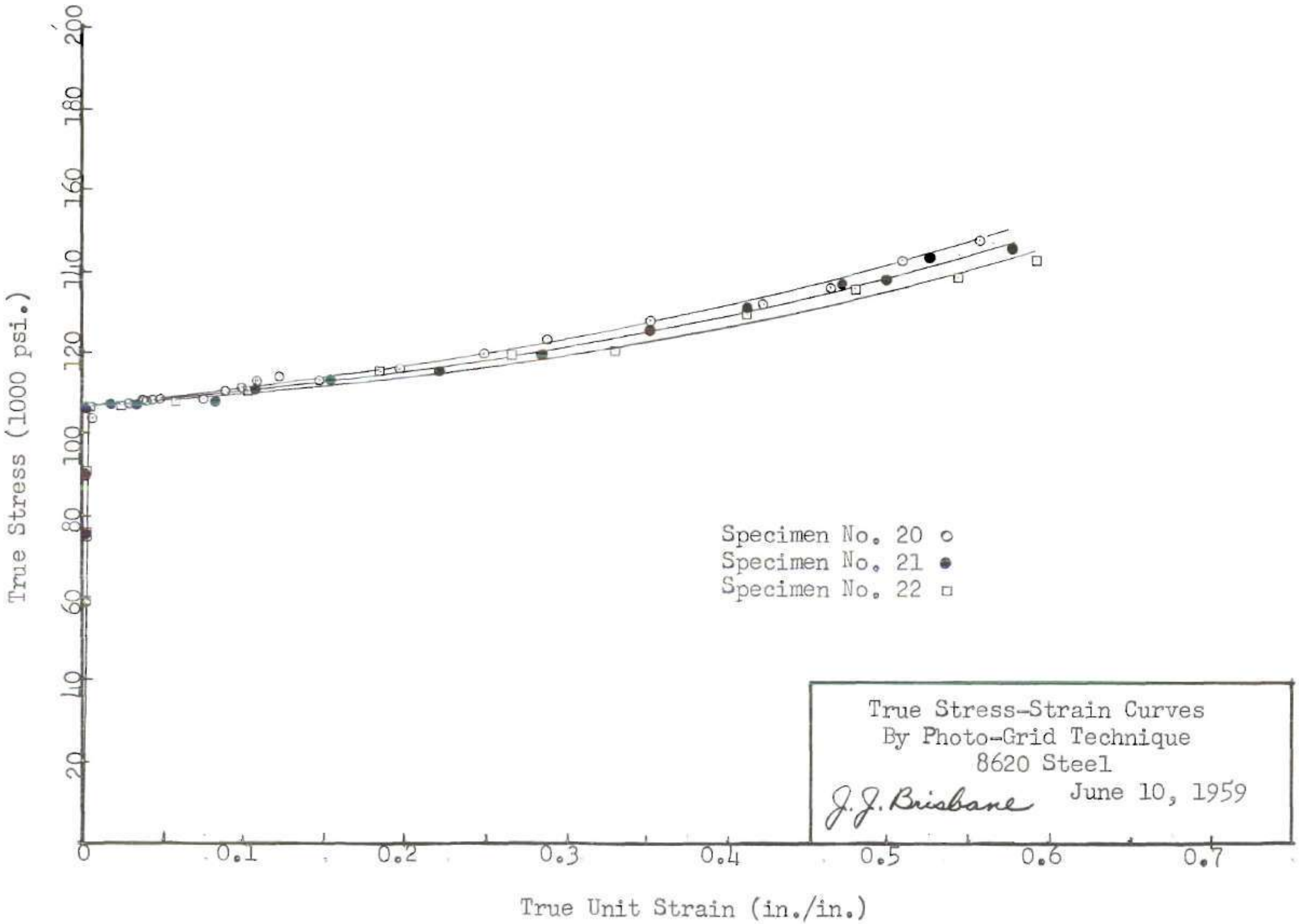
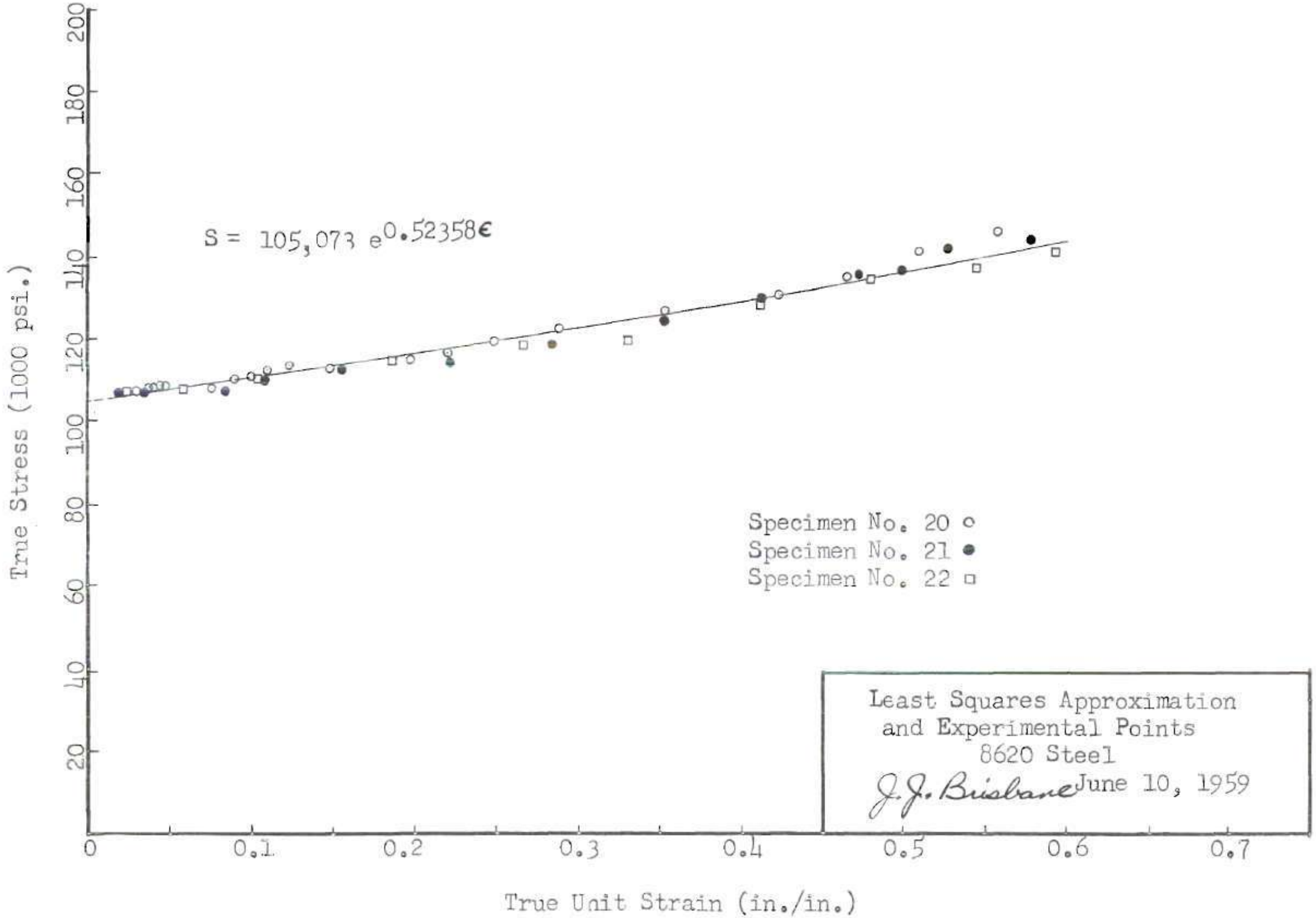
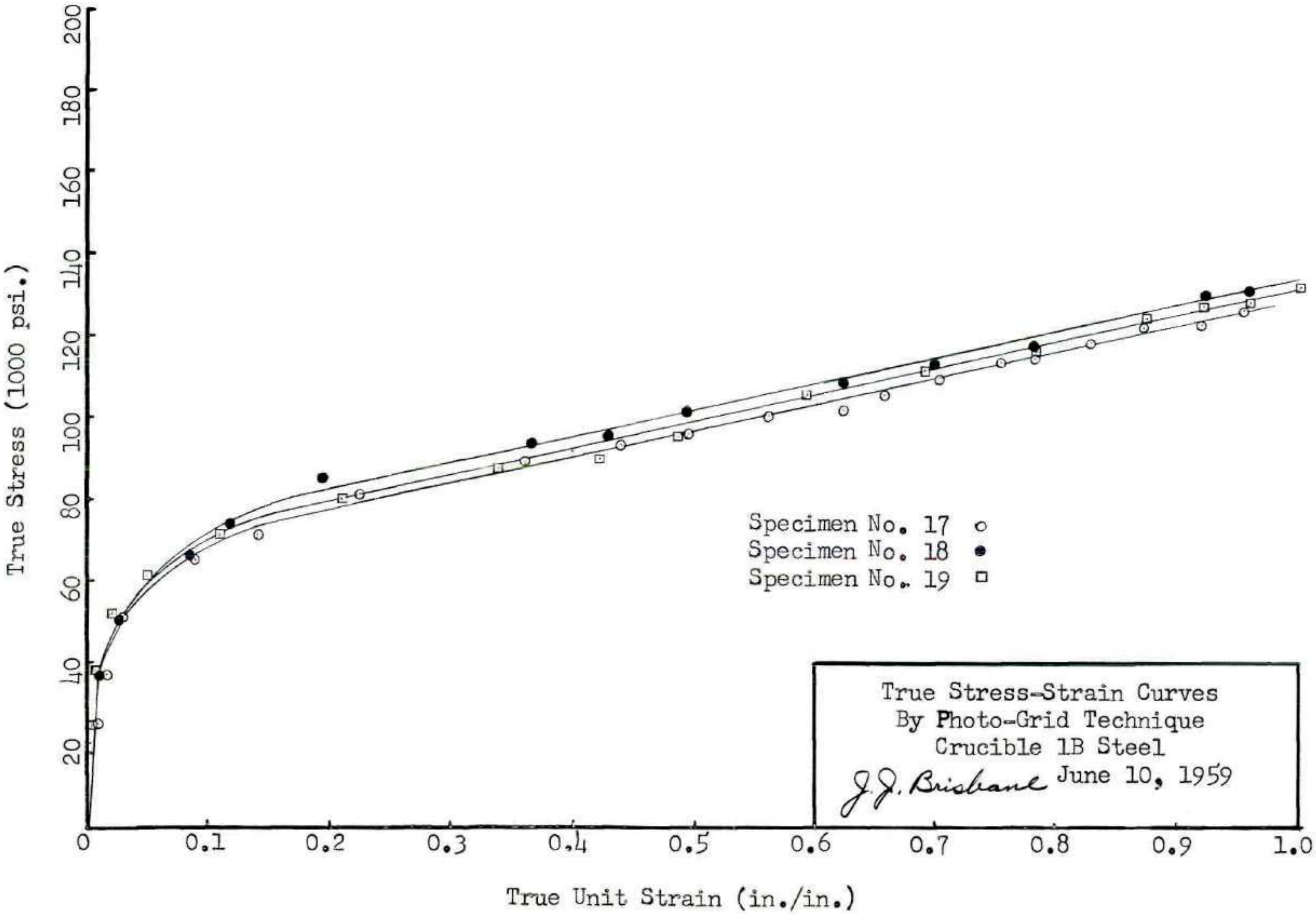

True Stress (1000 psi.)
200
180
160
140
120
100
80
60
40
20
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
True Unit Strain (in./in.)
Specimen No. 20 ○
Specimen No. 21 ●
Specimen No. 22 □
True Stress-Strain Curves
By Photo-Grid Technique
8620 Steel
J. J. Brisbane
June 10, 1959

Figure 11



$S = 105{,}073\ e^{0.52358\epsilon}$
True Stress (1000 psi.)
200
180
160
140
120
100
80
60
40
20
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
True Unit Strain (in./in.)
Specimen No. 20 ○
Specimen No. 21 ●
Specimen No. 22 □
Least Squares Approximation
and Experimental Points
8620 Steel
J. J. Brisbane June 10, 1959

Figure 12



True Stress (1000 psi.)
200
180
160
140
120
100
80
60
40
20
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
True Unit Strain (in./in.)
Specimen No. 17
Specimen No. 18
Specimen No. 19
True Stress-Strain Curves
By Photo-Grid Technique
Crucible 1B Steel
J. J. Brisbane June 10, 1959

Figure 13

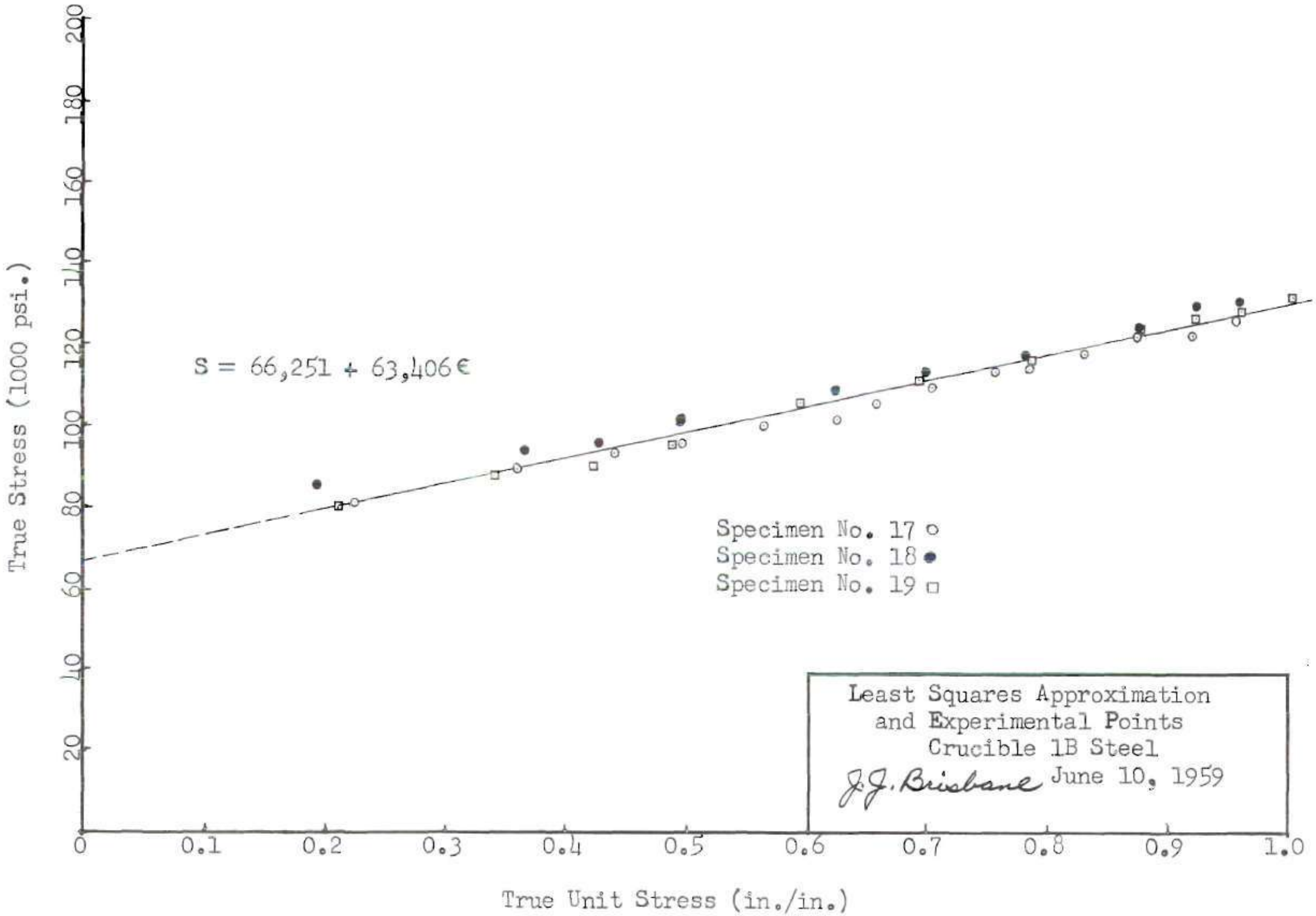

S = 66,251 + 63,406 €
True Stress (1000 psi.)
200
180
160
140
120
100
80
60
40
20
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Specimen No. 17 ○
Specimen No. 18 ●
Specimen No. 19 □
Least Squares Approximation
and Experimental Points
Crucible 1B Steel
J.J. Brisbane June 10, 1959
True Unit Stress (in./in.)

Figure 14

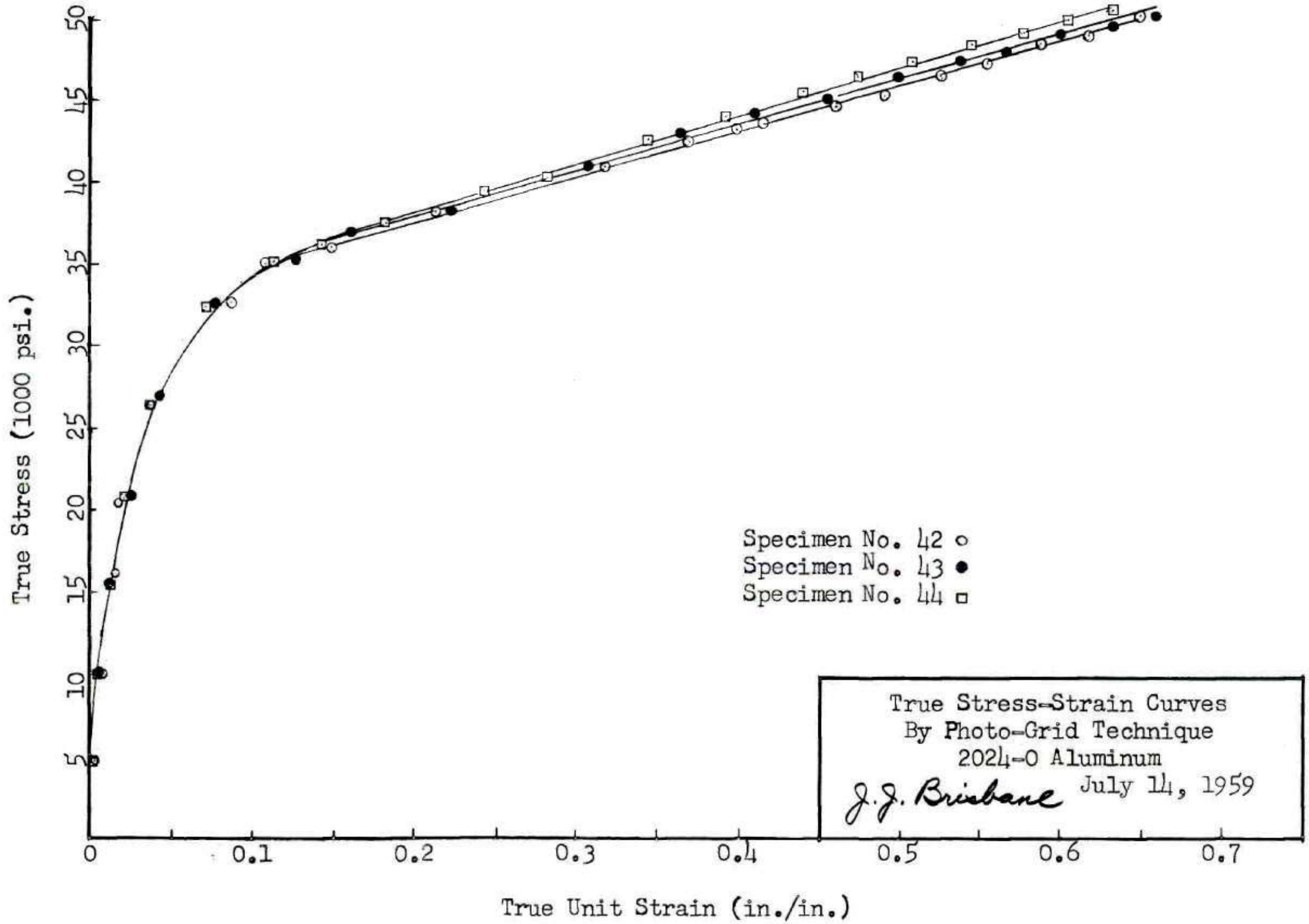

True Stress (1000 psi.)
5
10
15
20
25
30
35
40
45
50
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
True Unit Strain (in./in.)
Specimen No. 42 ○
Specimen No. 43 ●
Specimen No. 44 □
True Stress-Strain Curves
By Photo-Grid Technique
2024-0 Aluminum
J. J. Brisbane
July 14, 1959

Figure 15

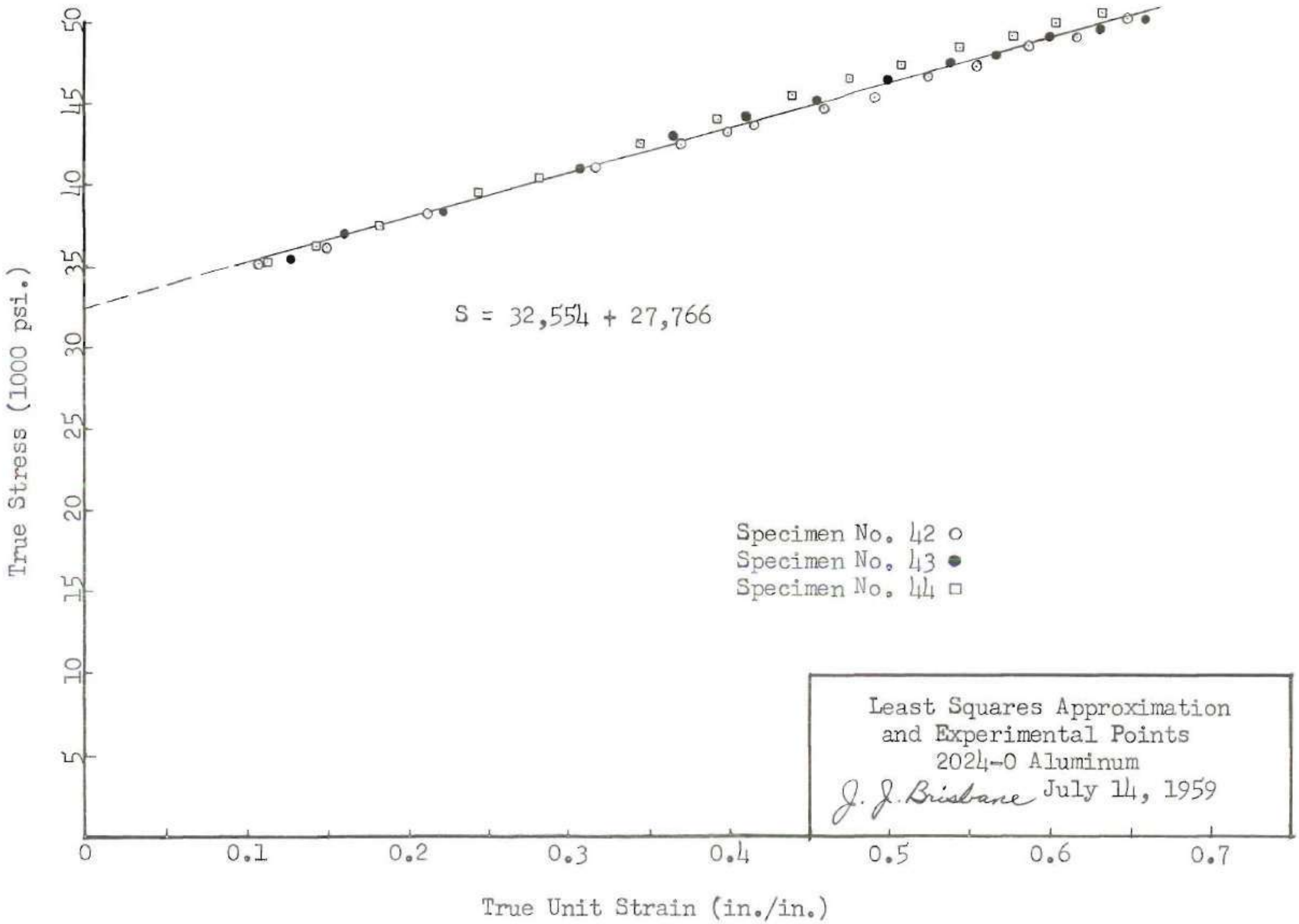

True Stress (1000 psi.)
0
5
10
15
20
25
30
35
40
45
50
S = 32,554 + 27,766
Specimen No. 42 ○
Specimen No. 43 ●
Specimen No. 44 □
Least Squares Approximation
and Experimental Points
2024-0 Aluminum
J. J. Brisbane July 14, 1959
0.1
0.2
0.3
0.4
0.5
0.6
0.7
True Unit Strain (in./in.)

Figure 16

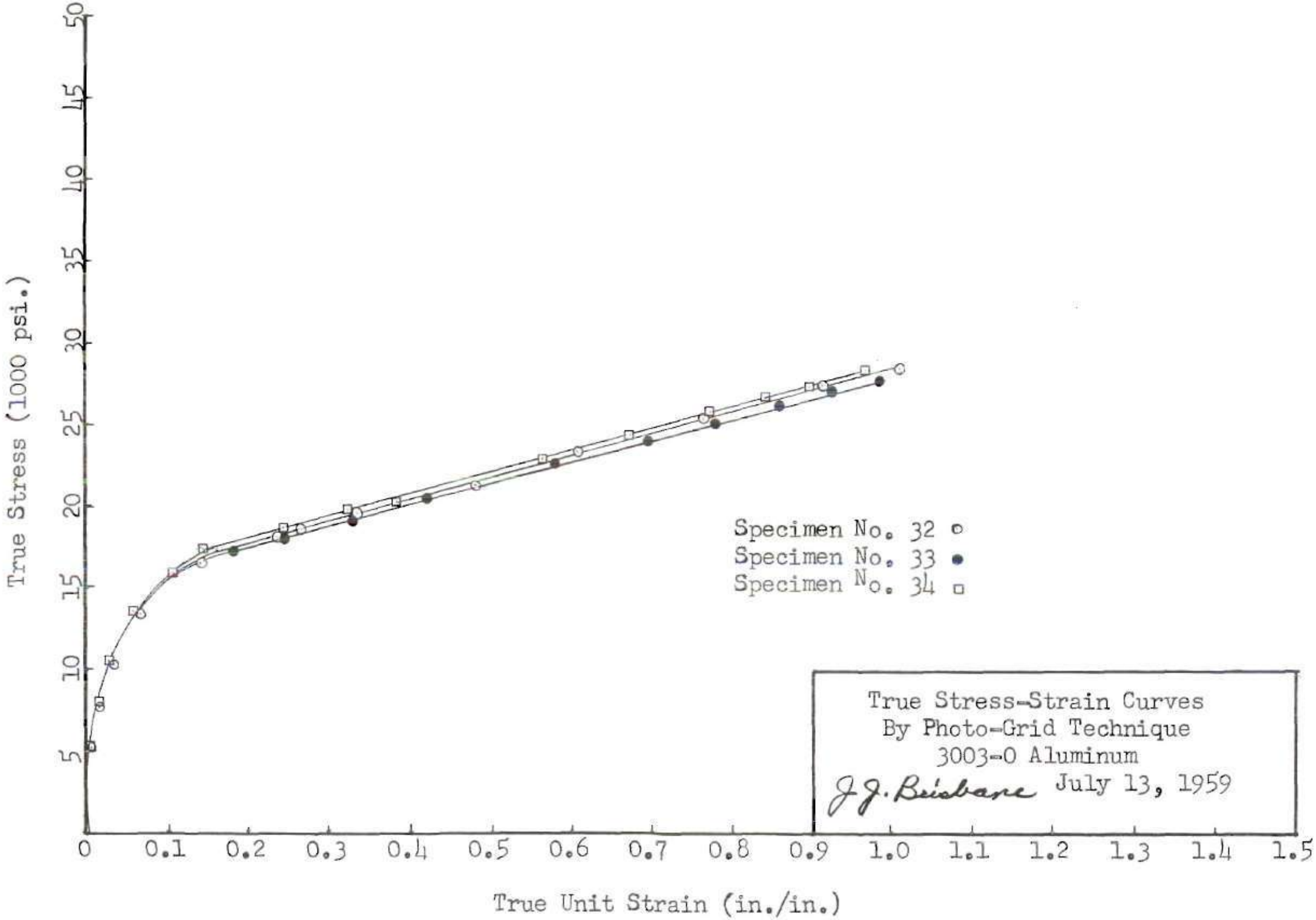

True Stress (1000 psi.)
5
10
15
20
25
30
35
40
45
50
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
True Unit Strain (in./in.)
Specimen No. 32
Specimen No. 33
Specimen No. 34
True Stress-Strain Curves
By Photo-Grid Technique
3003-0 Aluminum
J.J. Brisbane July 13, 1959

Figure 17

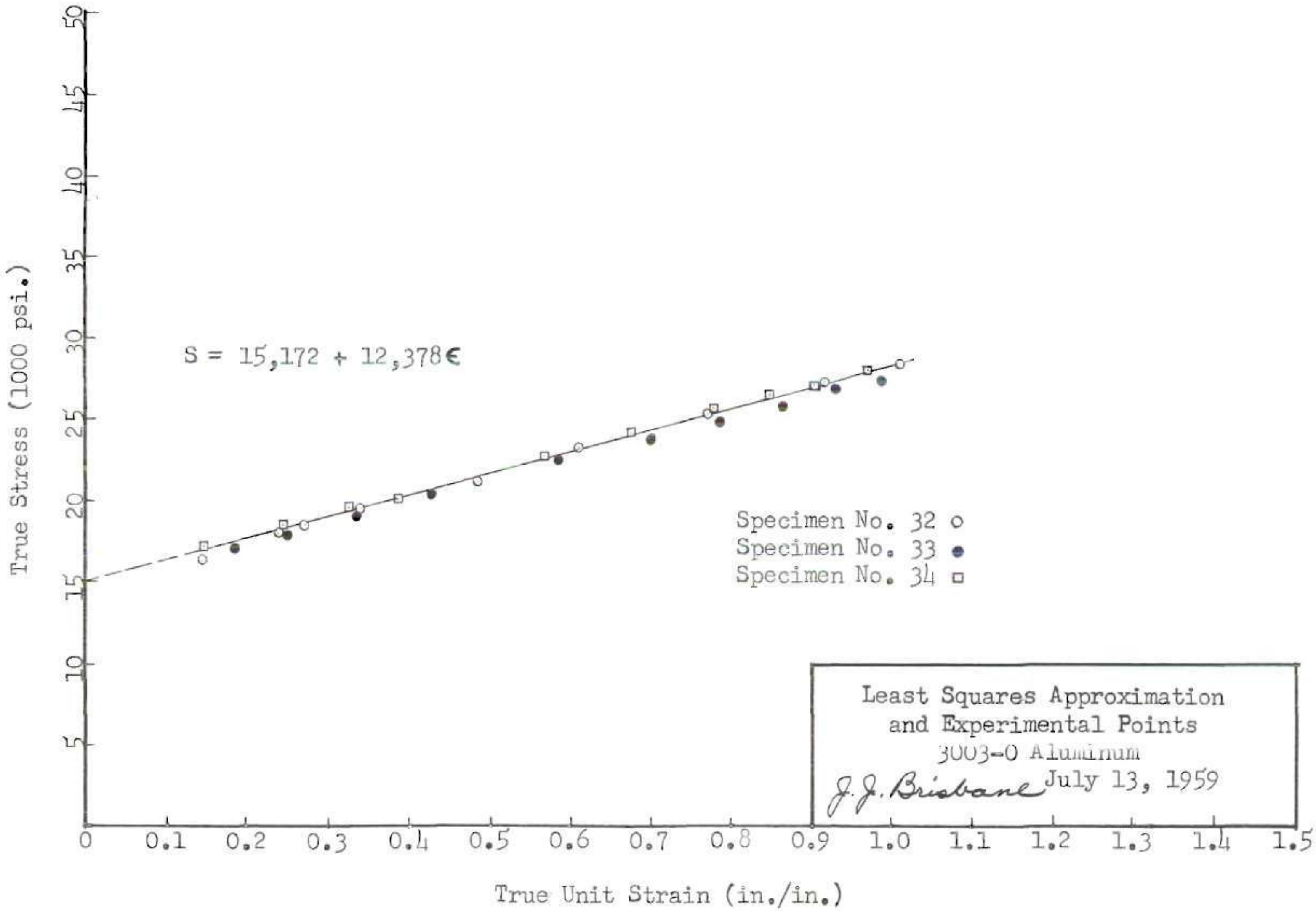

S = 15,172 + 12,378€
Specimen No. 32 o
Specimen No. 33 ●
Specimen No. 34 □
Least Squares Approximation
and Experimental Points
3003-0 Aluminum
J. J. Brisbane July 13, 1959
True Stress (1000 psi.)
True Unit Strain (in./in.)
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4 1.5
5 10 15 20 25 30 35 40 45 50

Figure 18

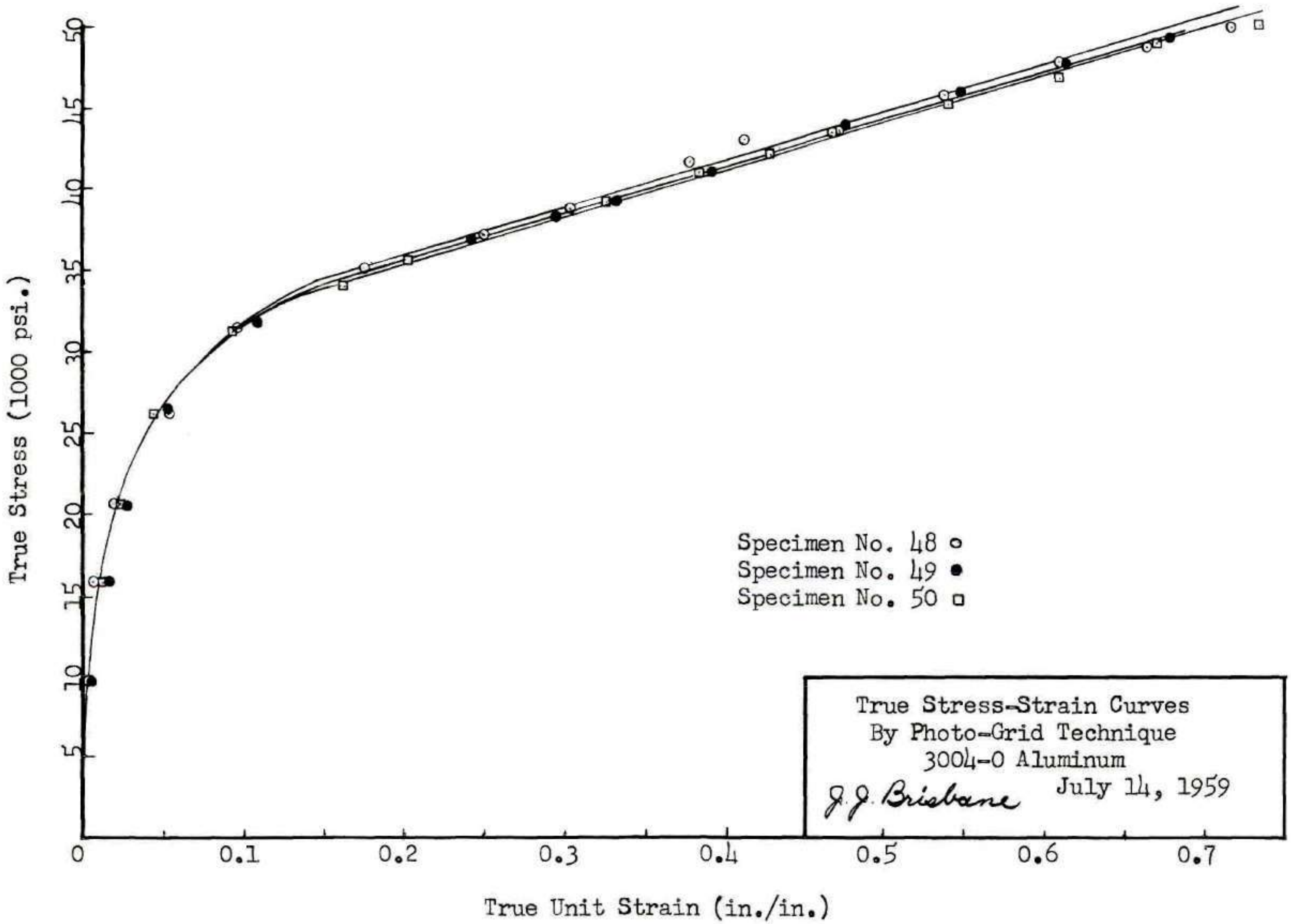

True Stress (1000 psi.)
5
10
15
20
25
30
35
40
45
50
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
True Unit Strain (in./in.)
Specimen No. 48 ○
Specimen No. 49 ●
Specimen No. 50 □
True Stress-Strain Curves
By Photo-Grid Technique
3004-0 Aluminum
J. J. Brisbane
July 14, 1959

Figure 19

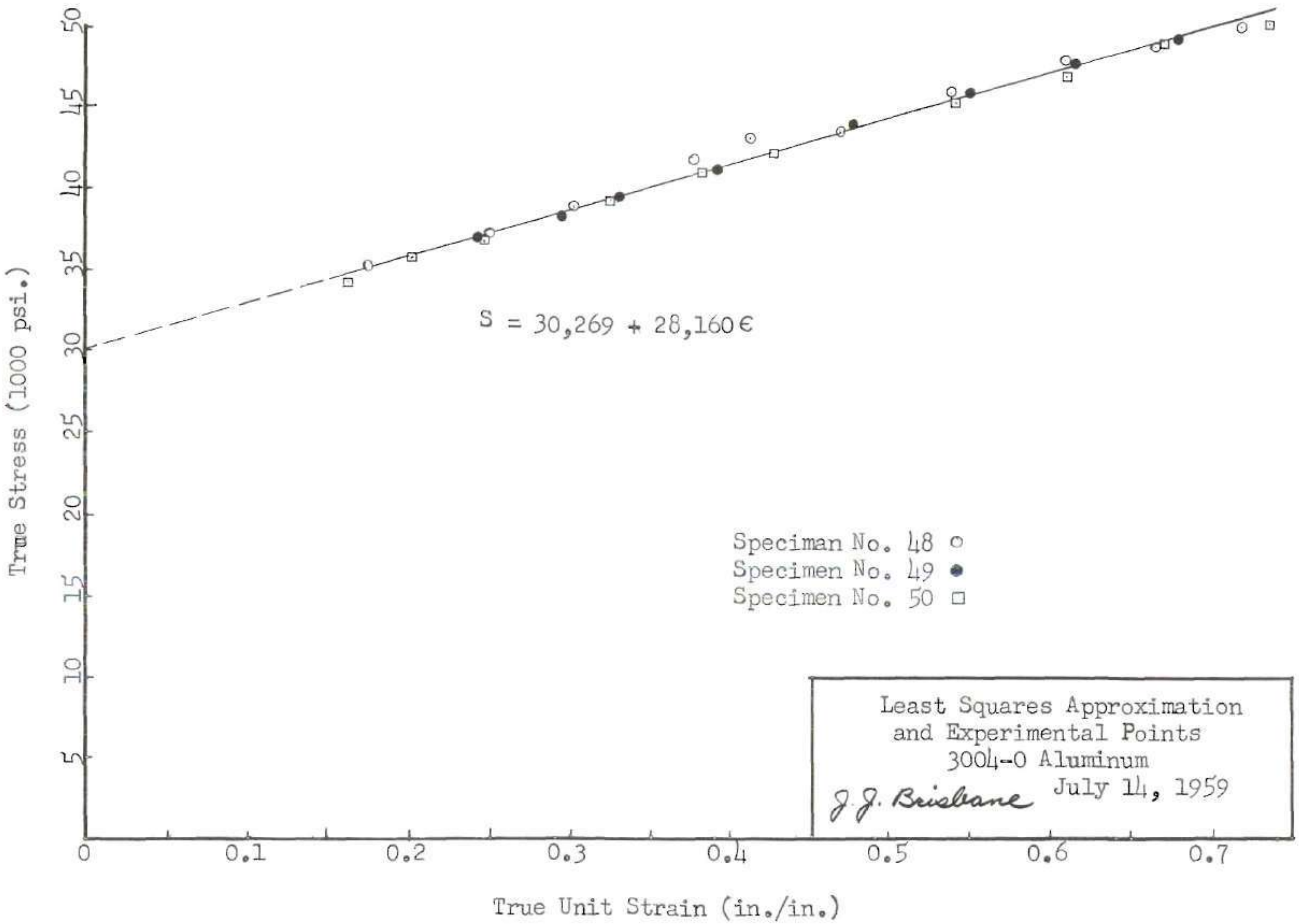

True Stress (1000 psi.)
50
45
40
35
30
25
20
15
10
5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
True Unit Strain (in./in.)
S = 30,269 + 28,160 ϵ
Speciman No. 48
Specimen No. 49
Specimen No. 50
Least Squares Approximation
and Experimental Points
3004-0 Aluminum
J. J. Brisbane
July 14, 1959

Figure 20

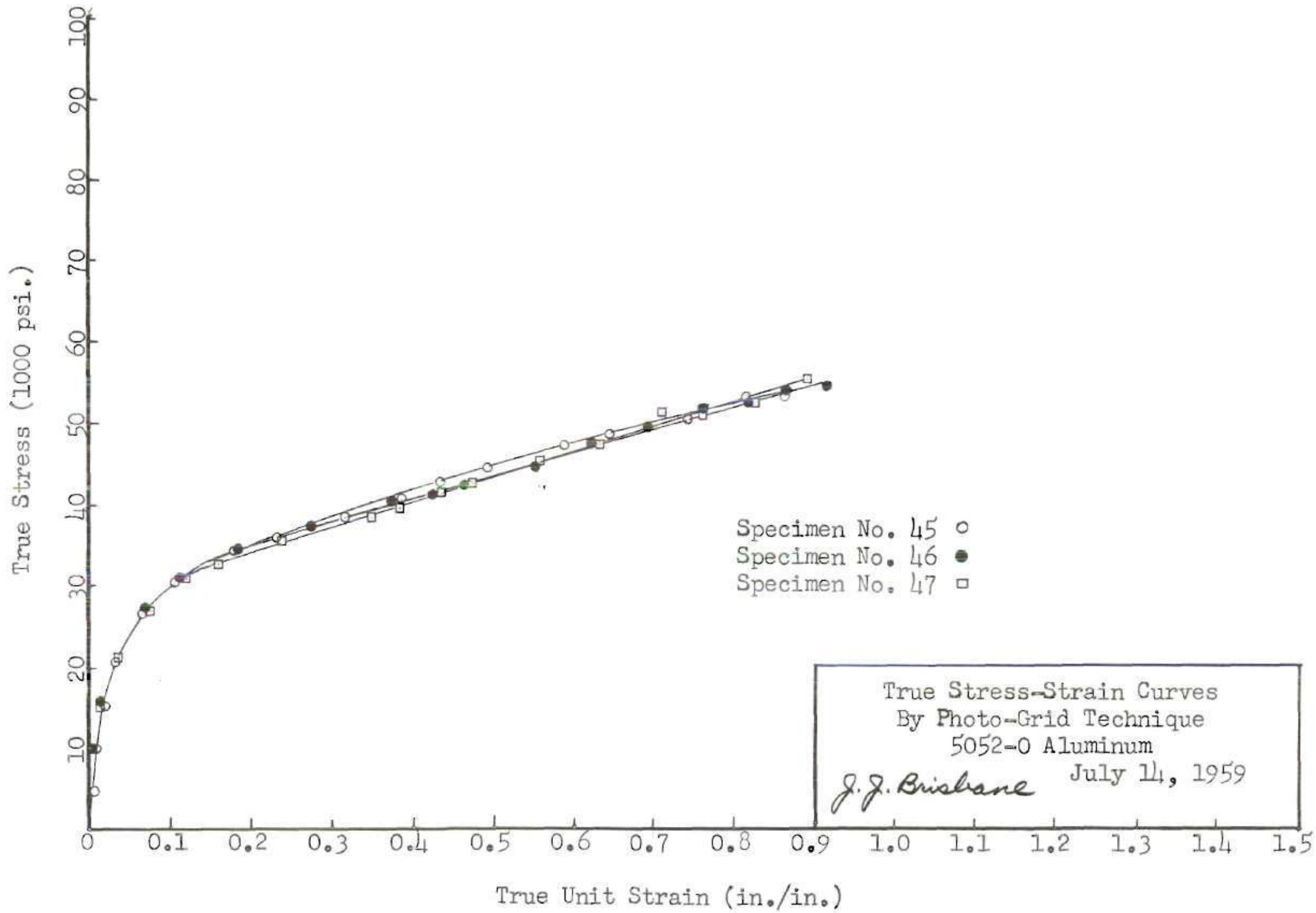

True Stress (1000 psi.)
0
10
20
30
40
50
60
70
80
90
100
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
True Unit Strain (in./in.)
Specimen No. 45 ○
Specimen No. 46 ●
Specimen No. 47 □
True Stress-Strain Curves
By Photo-Grid Technique
5052-O Aluminum
J. J. Brisbane
July 14, 1959

Figure 21

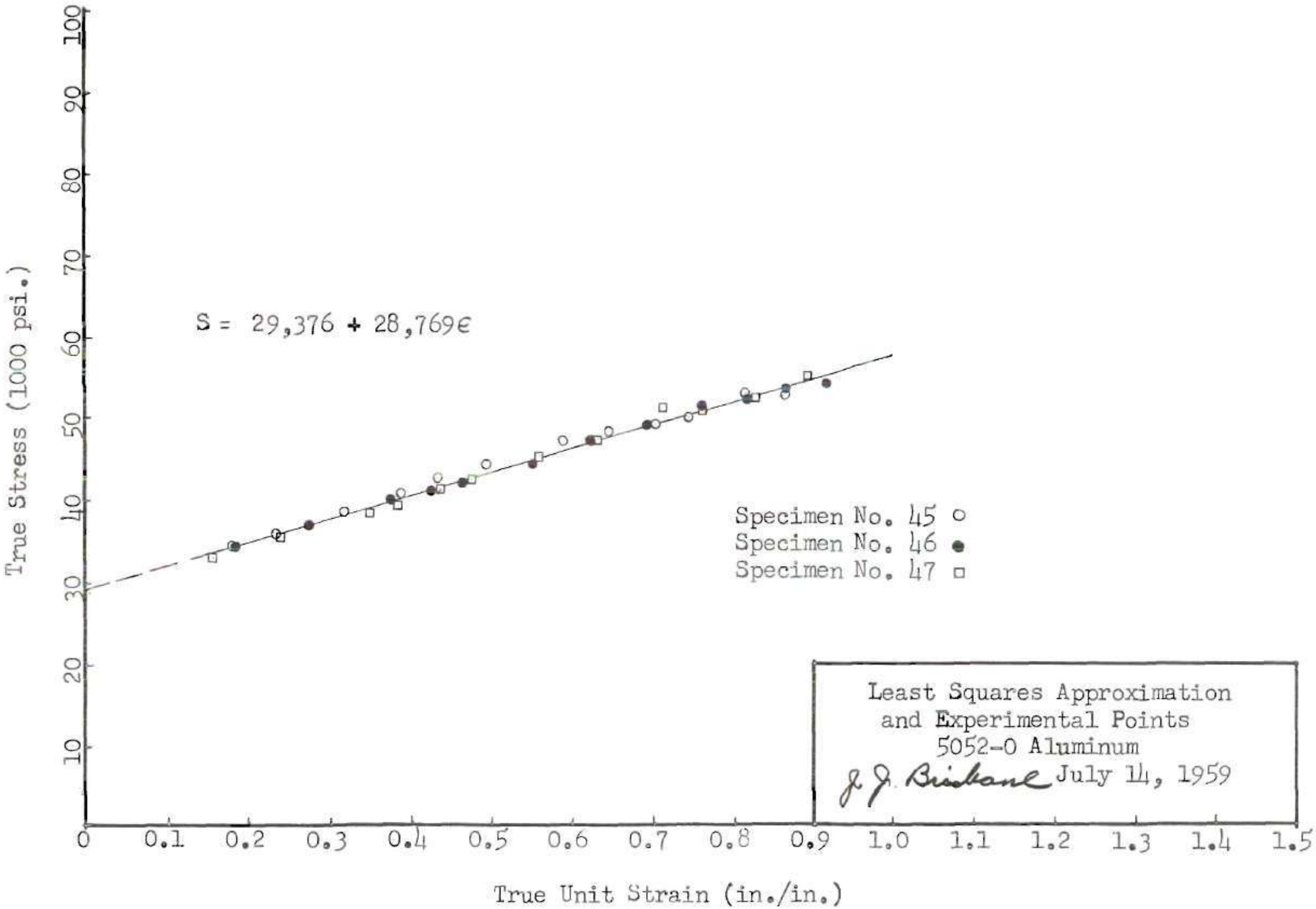

S = 29,376 + 28,769ϵ
True Stress (1000 psi.)
10
20
30
40
50
60
70
80
90
100
Specimen No. 45 ○
Specimen No. 46 ●
Specimen No. 47 □
Least Squares Approximation
and Experimental Points
5052-0 Aluminum
J. J. Briskane July 14, 1959
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
True Unit Strain (in./in.)

Figure 22

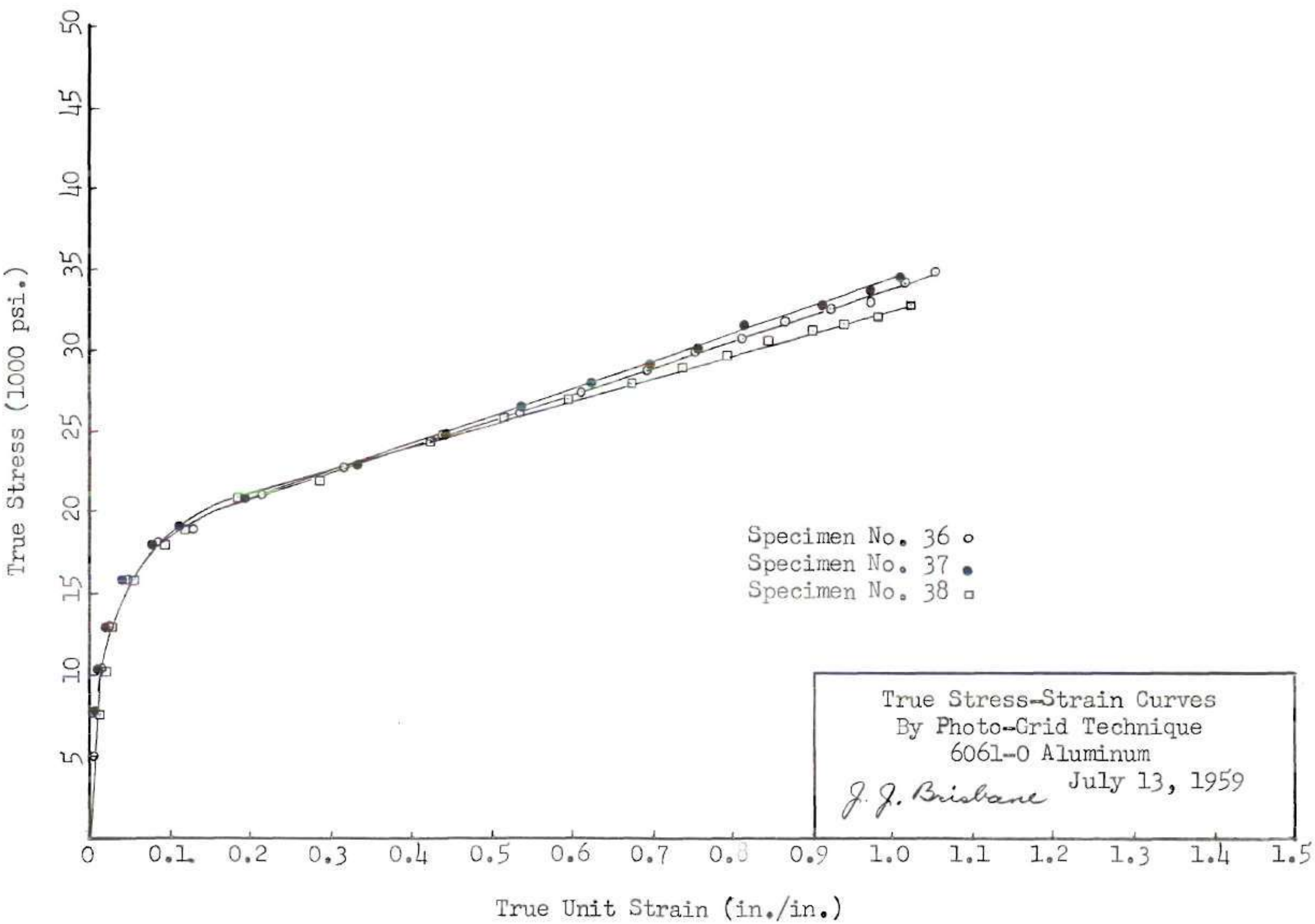
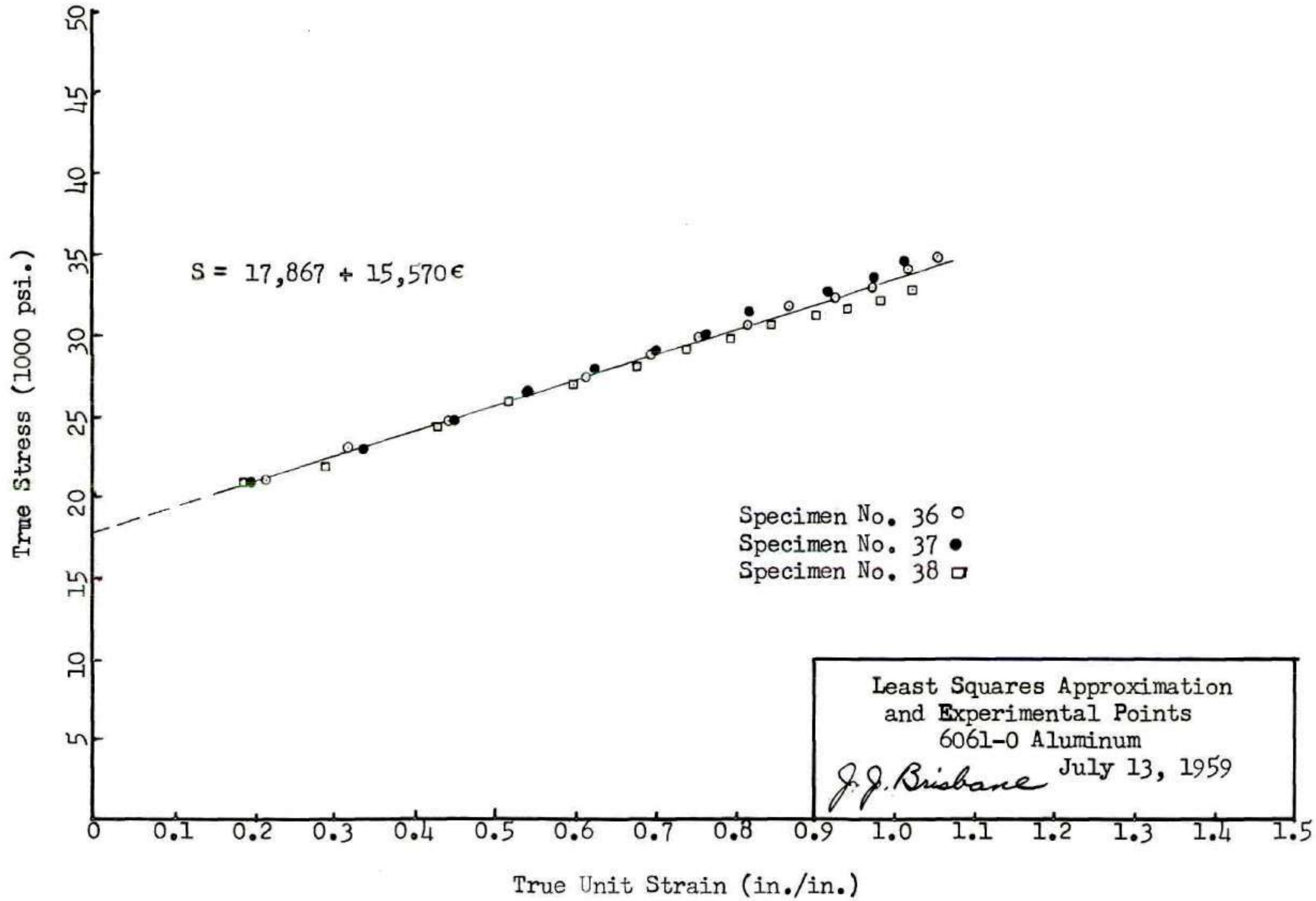

True Stress (1000 psi.)
5
10
15
20
25
30
35
40
45
50
True Unit Strain (in./in.)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
Specimen No. 36 o
Specimen No. 37 •
Specimen No. 38 □
True Stress-Strain Curves
By Photo-Grid Technique
6061-0 Aluminum
July 13, 1959
J. J. Brisbane

Figure 23



S = 17,867 + 15,570ε
True Stress (1000 psi.)
0
5
10
15
20
25
30
35
40
45
50
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
True Unit Strain (in./in.)
Specimen No. 36
Specimen No. 37
Specimen No. 38
Least Squares Approximation
and Experimental Points
6061-0 Aluminum
J. J. Brisbane
July 13, 1959

Figure 24

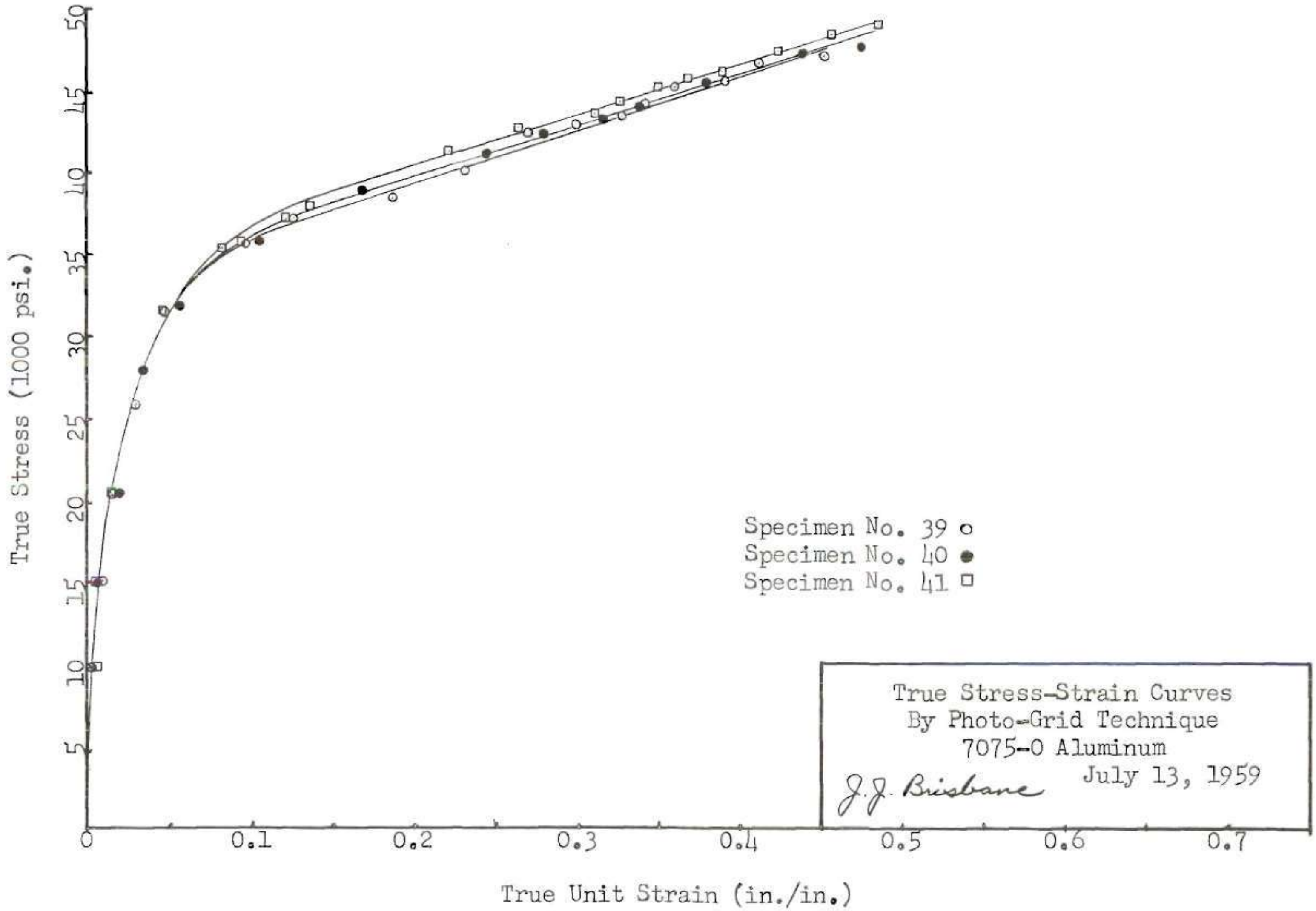

True Stress (1000 psi.)
True Unit Strain (in./in.)
Specimen No. 39 ○
Specimen No. 40 ●
Specimen No. 41 □
True Stress-Strain Curves
By Photo-Grid Technique
7075-0 Aluminum
J. J. Brisbane
July 13, 1959
0 5 10 15 20 25 30 35 40 45 50
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7

Figure 25

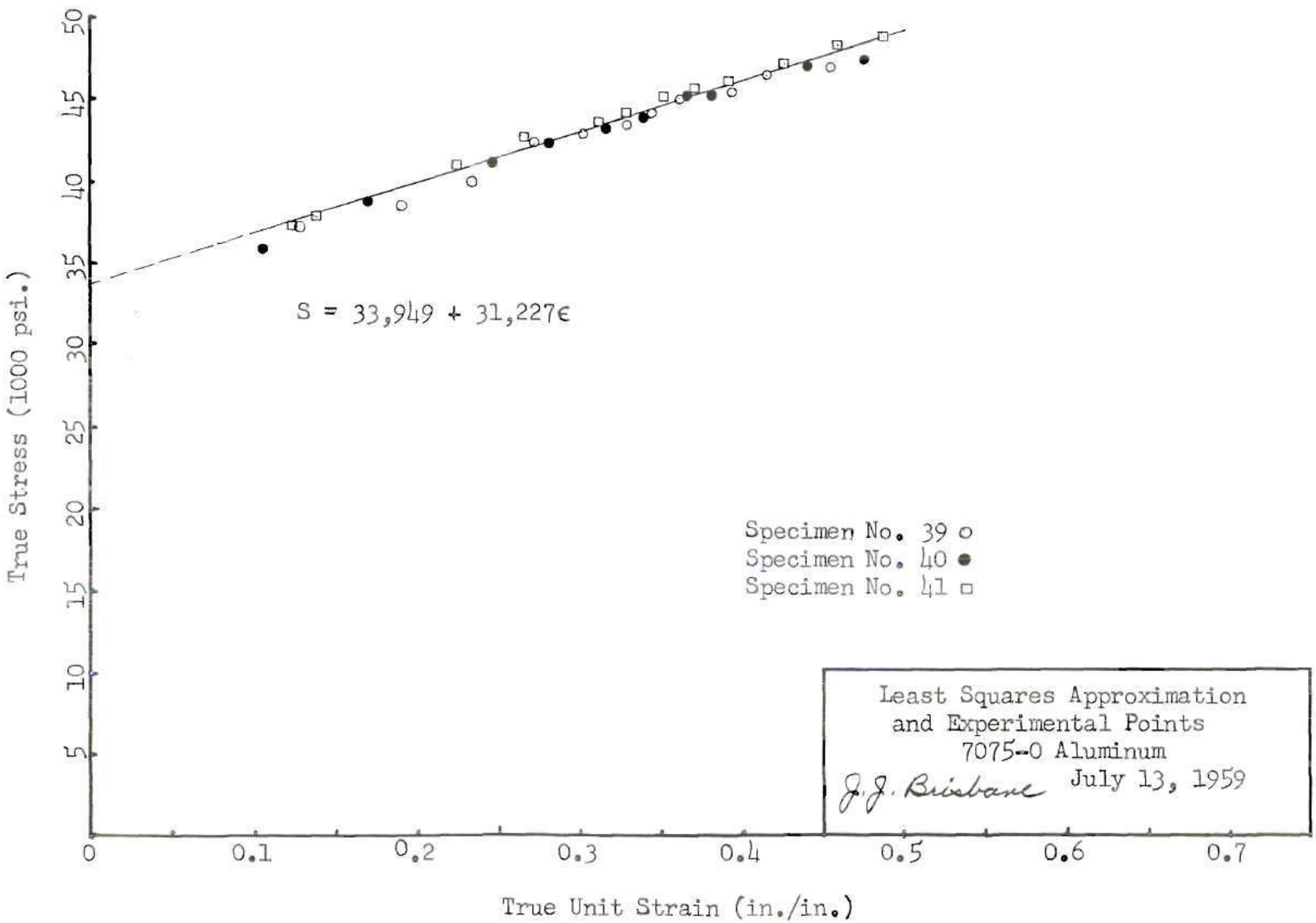

S = 33,949 + 31,227ϵ
Specimen No. 39 ○
Specimen No. 40 ●
Specimen No. 41 □
Least Squares Approximation
and Experimental Points
7075-0 Aluminum
J. J. Brisbane July 13, 1959
True Stress (1000 psi.)
True Unit Strain (in./in.)

Figure 26

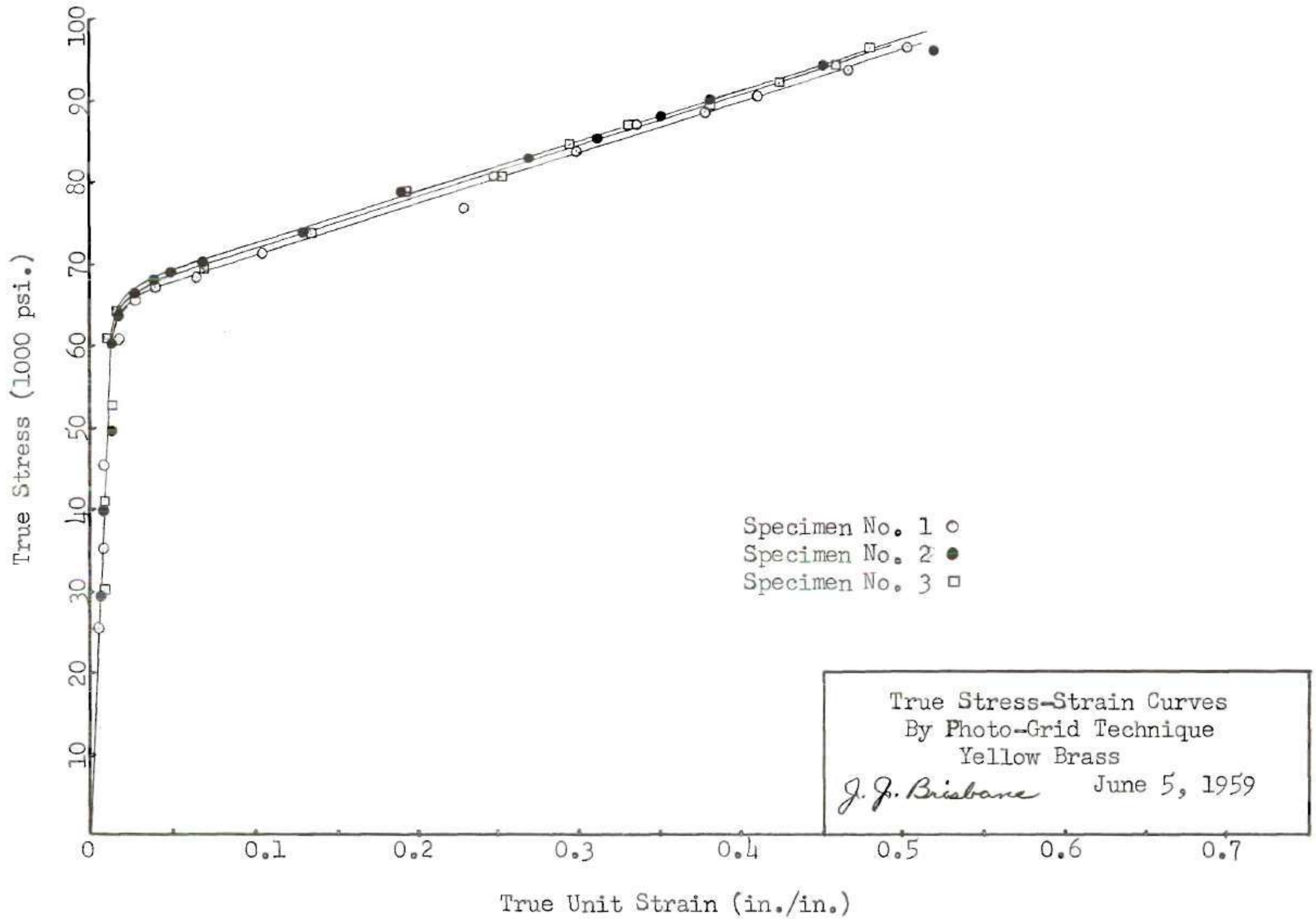

True Stress (1000 psi.)
100
90
80
70
60
50
40
30
20
10
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
True Unit Strain (in./in.)
Specimen No. 1 ○
Specimen No. 2 ●
Specimen No. 3 □
True Stress-Strain Curves
By Photo-Grid Technique
Yellow Brass
J. J. Brisbane
June 5, 1959

Figure 27

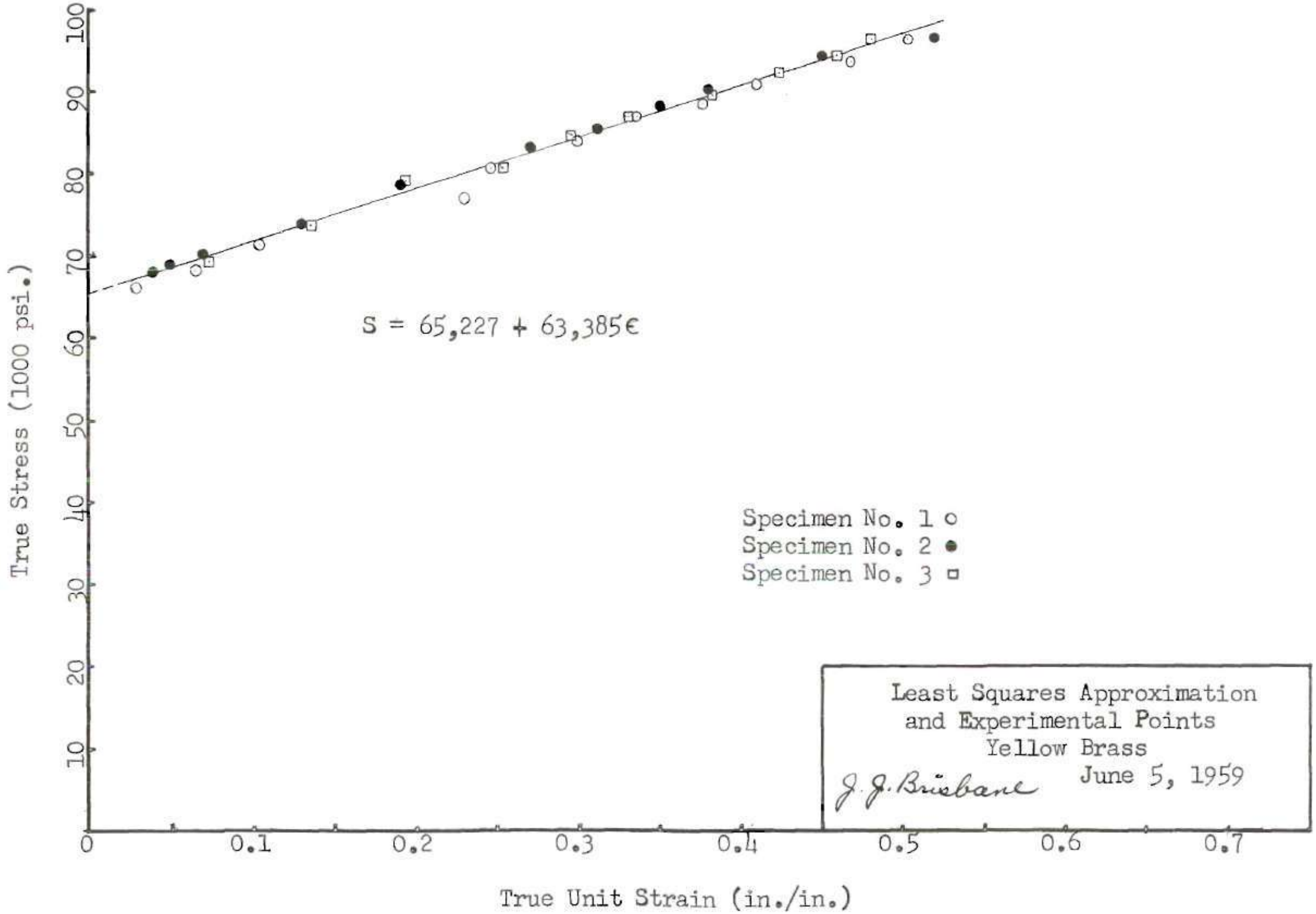

True Stress (1000 psi.)
100
90
80
70
60
50
40
30
20
10
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
True Unit Strain (in./in.)
S = 65,227 + 63,385є
Specimen No. 1
Specimen No. 2
Specimen No. 3
Least Squares Approximation
and Experimental Points
Yellow Brass
J. J. Brisbane
June 5, 1959

Figure 28

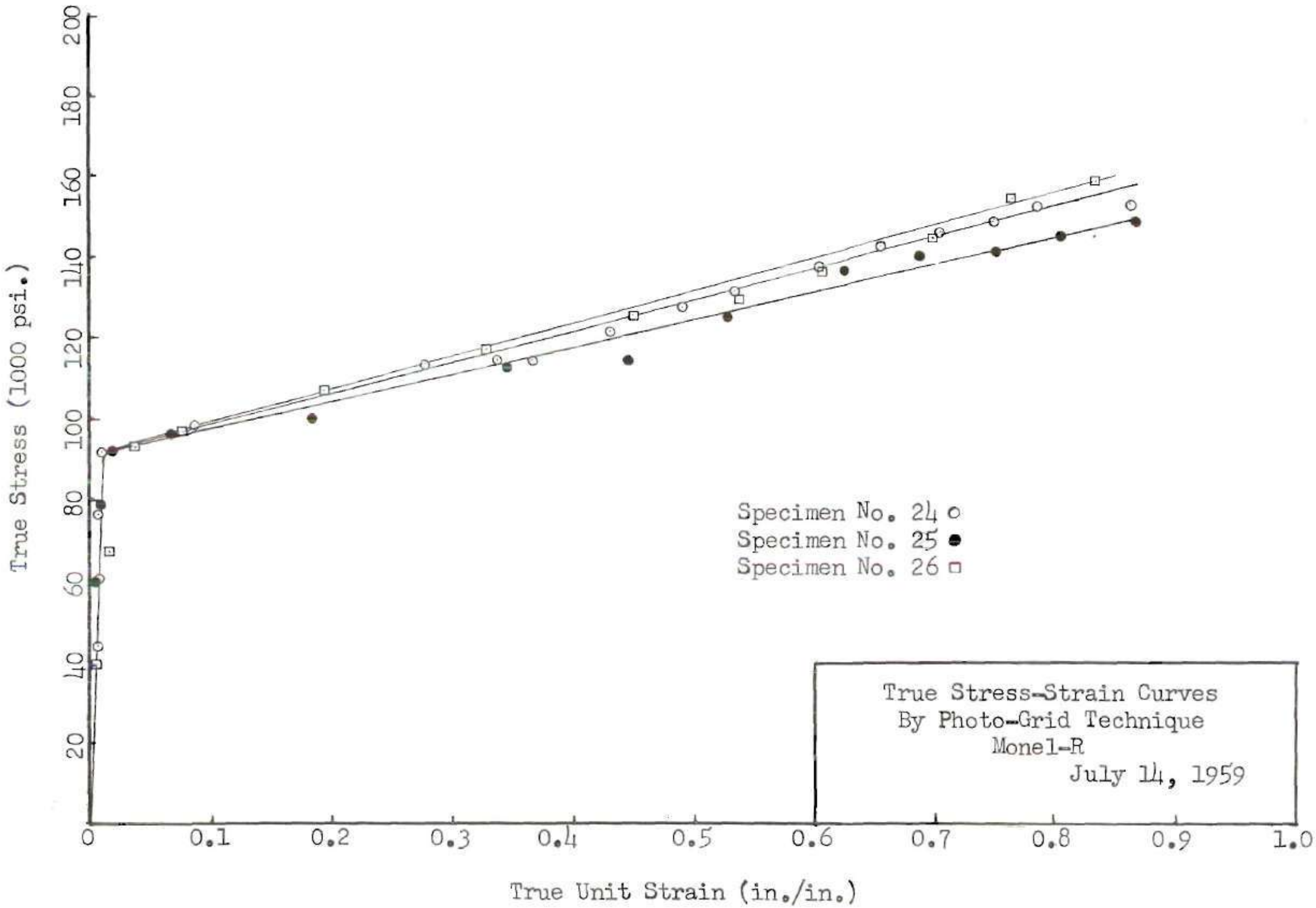
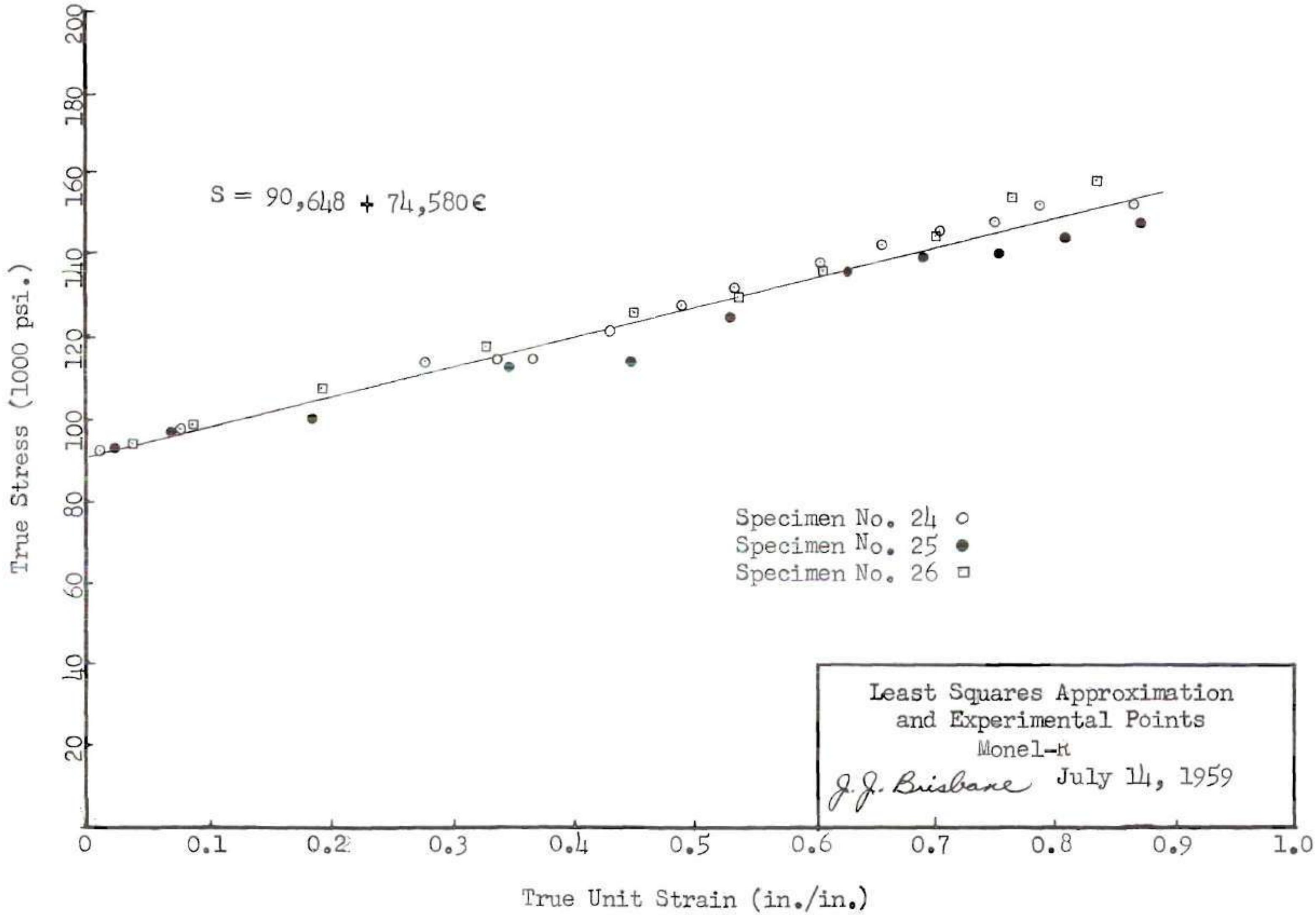

True Stress (1000 psi.)
True Unit Strain (in./in.)
Specimen No. 24
Specimen No. 25
Specimen No. 26
True Stress-Strain Curves
By Photo-Grid Technique
Monel-R
July 14, 1959

Figure 29



$S = 90,648 + 74,580\epsilon$
True Stress (1000 psi.)
200
180
160
140
120
100
80
60
40
20
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
True Unit Strain (in./in.)
Specimen No. 24
Specimen No. 25
Specimen No. 26
Least Squares Approximation
and Experimental Points
Monel-K
J. J. Brisbane July 14, 1959

Figure 30

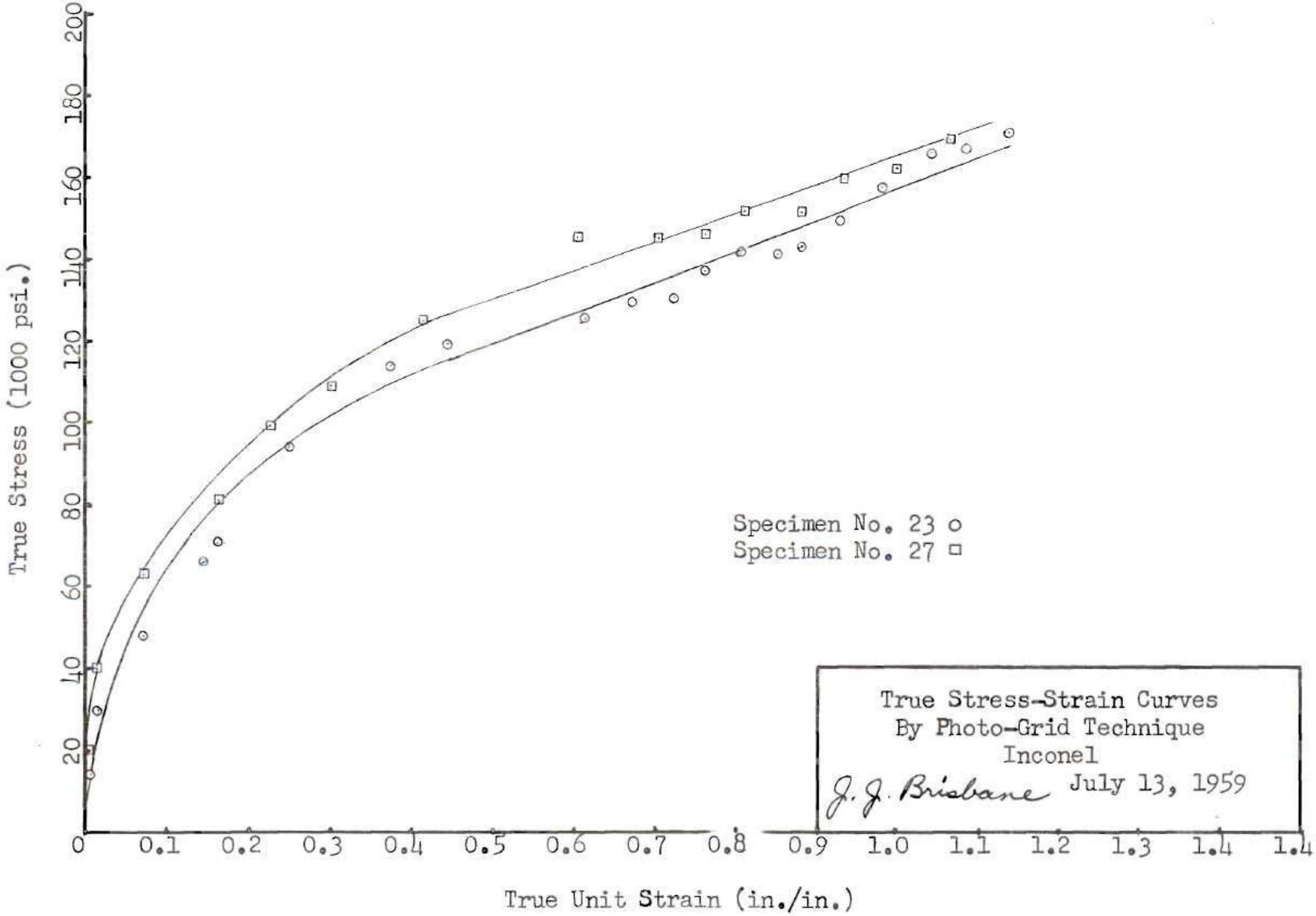

True Stress (1000 psi.)
200
180
160
140
120
100
80
60
40
20
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.4
True Unit Strain (in./in.)
Specimen No. 23 o
Specimen No. 27 □
True Stress-Strain Curves
By Photo-Grid Technique
Inconel
J. J. Brisbane July 13, 1959

Figure 31

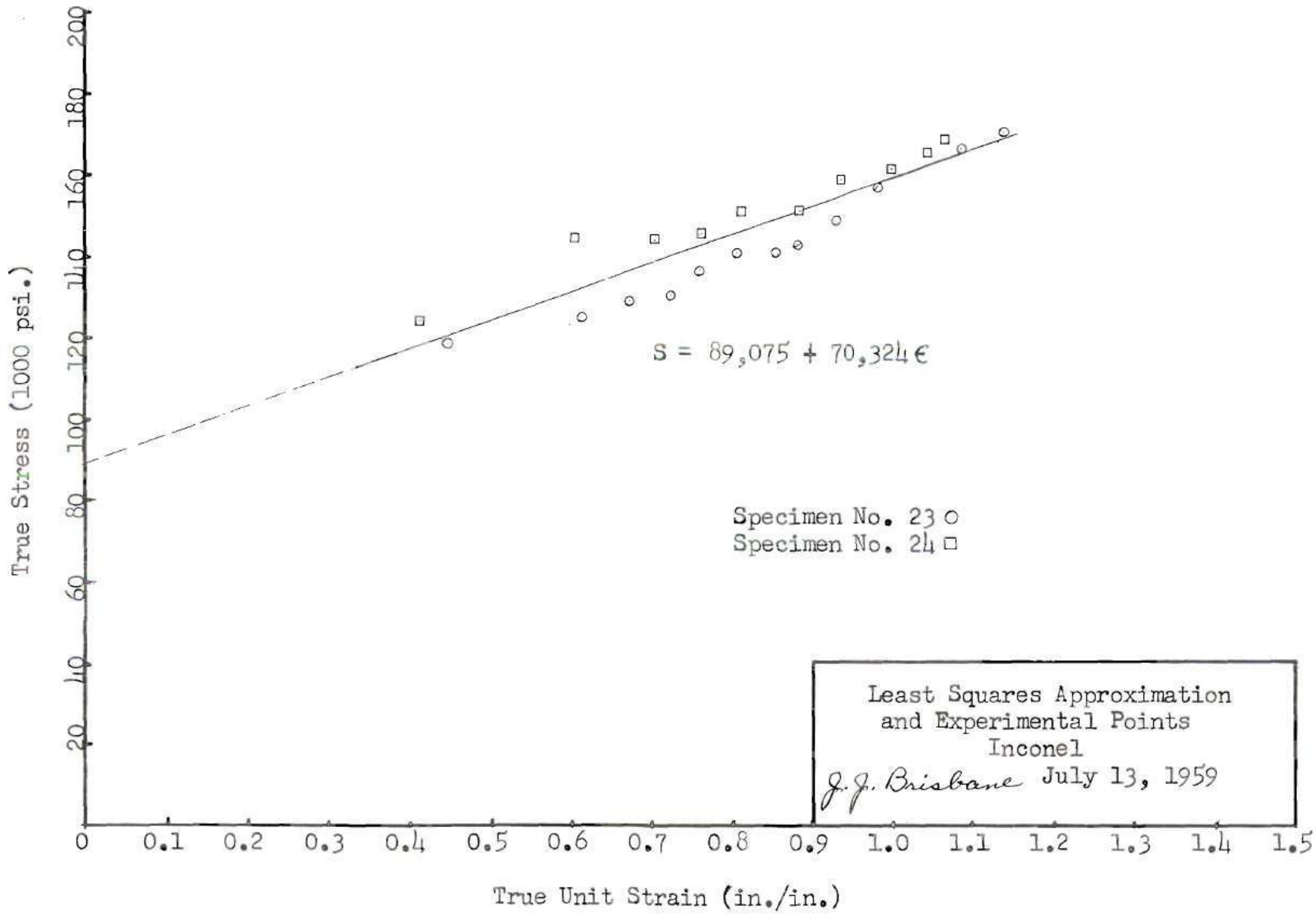

True Stress (1000 psi.)
200
180
160
140
120
100
80
60
40
20
S = 89,075 + 70,324 ϵ
Specimen No. 23 ○
Specimen No. 24 □
Least Squares Approximation
and Experimental Points
Inconel
J. J. Brisbane July 13, 1959
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
True Unit Strain (in./in.)

Figure 32

APPENDIX C

Included in this appendix is the experimental data. There is data from one specimen of each material included as typical data for that material

Table 2. Photo-Grid Data for Stress-Strain Relations

Specimen No. 9 Material: 1012 Steel

Initial Diameter = 0.5010 Inch

$K \times 4.247 = 0.5010$

$K = 0.1180$ $K^2 = 0.01392$ $\frac{K^2 \pi}{4} = 0.0109$

Frame No.	Load lbs.	Diam. mm.	Area sq.in.	Stress lbs./sq.in.	25 Lines mm.	Strain
1	Identification					
2	0	4.247	---	---	2,005	---
3	2,000	4.246	---	---	2.001	---
4	4,000	4.234	---	---	2.013	---
5	6,000	4.240	---	---	2.006	---
6	8,000	4.212	0.1934	41,365	2.010	0.0024
7	7,400	4.198	0.1921	38,521	2.027	0.0109
8	10,000	3.963	0.1711	58,445	2.173	0.0837
9	11,000	3.858	0.1622	67,817	2.371	0.1825
10	11,110	3.691	0.1485	74,747	2.529	0.2613
11	11,000	3.636	0.1441	76,335	2.715	0.3541
12	10,750	3.430	0.1282	83,853	2.995	0.4937
13	10,500	3.280	0.1173	89,514	3.179	0.5865
14	10,250	3.165	0.1092	93,864	3.326	0.6588
15	10,000	3.063	0.1023	97,751	3.470	0.7306
16	9,250	2.870	0.0898	103,000	3.782	0.8862
17	8,750	2.698	0.0793	110,340	3.989	0.9895
18	8,250	2.564	0.0717	115,060	4.143	1.0663
19	7,750	2.471	0.0666	116,370	4.312	1.1506
20	7,500	(Fracture)				

Table 3. Photo-Grid Data for Stress-Strain Relations

Specimen No. 6 Material: 1020 Steel

Initial Diameter = 0.5010 inch

$K \times 4.138 = 0.5010$

$K = 0.1211$ $K^2 = 0.01467$ $\frac{K^2\pi}{4} = 0.0115$

Frame No.	Load lbs.	Diam. mm.	Area sq.in.	Stress lbs./sq.in.	25Lines mm.	Strain mm./mm
1	Identification					
2	0	4.138	0.1969	0	2.082	0.0000
3	2,500	4.135	0.1966	12,716	2.094	0.0057
4	5,000	4.130	0.1962	25,484	2.098	0.0076
5	7,500	4.129	0.1961	38,246	2.108	0.0125
6	8,800	4.105	0.1938	45,408	2.130	0.0231
7	10,000	4.055	0.1891	52,882	2.159	0.0370
8	12,000	3.996	0.1836	65,359	2.231	0.0716
9	13,400	3.808	0.1668	80,336	2.543	0.2214
10	13,250	3.580	0.1474	89,891	2.840	0.3641
11	12,750	3.381	0.1315	96,958	3.096	0.4870
12	12,500	3.313	0.1261	99,049	3.230	0.5514
13	12,250	3.209	0.1183	103,550	3.354	0.6110
14	12,000	3.135	0.1130	106,190	3.453	0.6585
15	11,500	2.993	0.1030	111,650	3.663	0.7594
16	11,000	2.877	0.0952	115,860	3.804	0.8271
17	10,500	2.764	0.0879	119,450	3.953	0.8987
18	10,250	2.723	0.0853	120,170	4.057	0.9486
19	10,050	(Fracture)				

Table 4. Photo-Grid Data for Stress-Strain Relations

Specimen No. 12 Material: 1042 Steel

Initial Diameter = 0.5023 inch

$K \times 4.155 = 0.5023$

$K = 0.1209$ $K^2 = 0.01462$ $\frac{K^2\pi}{4} = 0.01148$

Frame No.	Load lbs.	Diam. mm.	Area sq.in.	Stress lbs./sq.in.	25 Lines mm.	Strain mm/mm.
1	Identification					
2	0	4.155	0.1982	0	2.058	0.0000
3	2,500	—	—	—	—	—
4	5,000	—	—	—	—	—
5	7,500	—	—	—	—	—
6	10,000	4.145	0.1972	50,709	2.075	0.0082
7	12,500	4.122	0.1951	64,069	2.095	0.0179
8	15,000	4.102	0.1932	77,639	2.142	0.0408
9	17,500	4.003	0.1840	95,110	2.283	0.1193
10	17,700	3.921	0.1765	100,280	2.451	0.1909
11	17,500	3.713	0.1583	110,550	2.654	0.2896
12	17,250	3.640	0.1521	113,410	2.735	0.3289
13	17,100	3.606	0.1493	114,534	2.800	0.3605
14	16,900	3.523	0.1425	118,600	2.865	0.3921
15	16,700	3.494	0.1401	119,200	2.935	0.4261
16	16,500	3.457	0.1372	120,260	2.982	0.4489
17	16,300	3.413	0.1337	121,910	3.050	0.4820
18	16,100	3.360	0.1296	124,228	3.096	0.5043
19	15,900	3.314	0.1261	126,090	3.148	0.5296
20	15,700	(Fracture)				

Table 5. Photo-Grid Data for Stress-Strain Relations

Specimen No. 15 Material: 1095 Steel

Initial Diameter = 0.5024 inch

$K \times 4.207 = 0.5024$

$K = 0.11942$ $K^2 = 0.014261$ $\frac{K^2 \pi}{4} = 0.0112$

Frame No.	Load lbs.	Diam. mm.	Area sq.in.	Stress lbs./sq.in.	25 Lines mm.	Strain mm./mm.
1	Identification					
2	0	4.207	0.1982	0	2.120	0.0000
3	4,000	4.205	0.1980	20,202	2.123	0.0014
4	8,000	4.206	0.1979	40,424	2.128	0.0037
5	12,000	4.199	0.1975	60,759	2.141	0.0099
6	16,000	4.173	0.1950	82.051	2.152	0.0150
7	20,000	4.168	0.1946	102,770	2.172	0.0245
8	24,000	4.134	0.1914	125,390	2.197	0.0364
9	26,000	4.124	0.1905	136,480	2.228	0.0509
10	27,000	4.098	0.1881	143,540	2.276	0.0735
11	27,400	4.068	0.1853	147,870	2.298	0.0839
12	27,500	4.039	0.1827	150,520	2.338	0.1028
13	27,500	4.033	0.1822	150,930	2.350	0.1084
14	27,500	3.995	0.1788	153,800	2.384	0.1245
15	27,400	3.990	0.1783	153,670	2.426	0.1443
16	27,350	3.983	0.1777	153,910	2.434	0.1481
17	27,300	(Fracture)				

Table 6. Photo-Grid Data for Stress-Strain Relations

Specimen No. 21

Material: 8620 Steel

Initial Diameter=0.5040 inch

$K \times 4.197 = 0.5040$

$K = 0.12008$ $K^2 = 0.01442$ $\frac{K^2\pi}{4} = 0.1133$

Frame No.	Load lbs.	Diam. mm.	Area sq.in.	Stress lbs./sq.in.	25 Lines mm.	Strain mm./mm
1	Identification					
2	0	4.197	0.1996	0	2.093	0.0000
3	3,000	—	—	—	—	—
4	6,000	—	—	—	—	—
5	9,000	—	—	—	—	—
6	12,000	—	—	—	—	—
7	15,000	4.192	0.1991	75,339	2.098	0.0023
8	18,000	4.193	0.1991	90,406	2.101	0.0038
9	21,000	4.175	0.1975	106,330	2.107	0.0066
10	21,110	4.170	0.1970	107,110	2.134	0.0195
11	20,500	4.102	0.1906	107,560	2.167	0.0353
12	20,000	4.055	0.1862	107,410	2.267	0.0831
13	19,500	3.950	0.1786	110,294	2.320	0.1084
14	19,000	3.845	0.1675	113,430	2.418	0.1552
15	18,500	3.775	0.1615	114,550	2.556	0.2212
16	18,000	3.659	0.1517	118,660	2.688	0.2842
17	17,400	3.519	0.1403	124,020	2.831	0.3526
18	16,800	3.370	0.1287	130,540	2.957	0.4128
19	16,200	3.244	0.1192	135,910	3.081	0.4720
20	15,600	3.105	0.1092	142,860	3.197	0.5274
21	15,000	3.030	0.1040	144,230	3.304	0.5786
22	14,700	(Fracture)				

Table 7. Photo-Grid Data for Stress-Strain Relations

Specimen No. 17

Material: 1B Steel

Initial Diameter = 0.5036 inch

K 4.026 = 0.5036

$K = 0.12508$ $K^2 = 0.015645$ $\frac{K^2 \pi}{4} = 0.01229$

Frame No.	Load lbs.	Diam. mm.	Area sq.in.	Stress lbs./sq.in.	25 Lines mm.	Strain mm./mm.
1	Identification					
2	0	4.026	0.1992	0	1.990	0.0000
3	2,500	4.020	0.1986	12,588	1.994	0.0020
4	5,000	4.023	0.1989	25,138	2.007	0.0085
5	7,500	4.025	0.1991	37,662	2.020	0.0150
6	10,000	3.974	0.1941	51,517	2.047	0.0286
7	12,500	3.932	0.1900	65,783	2.166	0.0884
8	13,500	3.860	0.1879	71,845	2.263	0.1371
9	13,680	3.725	0.1705	80,234	2.439	0.2256
10	13,500	3.531	0.1532	88,120	2.707	0.3603
11	13,250	3.417	0.1435	92,334	2.865	0.4396
12	13,000	3.326	0.1360	95,588	2.974	0.4944
13	12,750	3.227	0.1279	99,687	3.112	0.5638
14	12,500	3.180	0.1243	100,560	3.233	0.6246
15	12,250	3.083	0.1168	104,880	3.301	0.6587
16	12,000	3.000	0.1106	108,500	3.393	0.7051
17	11,750	2.922	0.1049	112,010	3.494	0.7557
18	11,500	2.868	0.1011	113,750	3.552	0.7849
19	11,250	2.793	0.0959	117,310	3.640	0.8291
20	11,000	2.712	0.0904	121,681	3.729	0.8738
21	10,700	2.676	0.0880	121,590	3.823	0.9211
22	10,400	2.596	0.0828	125,603	3.895	0.9572
23	10,000	(Fracture)				

Table No. 8 Photo-Grid Data for Stress-Strain Relations

Specimen No. 42 Material: 2024-0 Aluminum

Initial Diameter $= 0.5006$ inch

$K \times 4.506 = 0.5006$

$K = 0.11109$ $K^2 = 0.012341$ $\frac{K^2\pi}{4} = 0.00969$

Frame No.	Load lbs.	Diam. mm.	Area sq.in.	Stress lbs./sq.in	25 Lines mm.	Strain mm./mm
1	Identification					
2	0	4.506	0.1967	0	2.256	0.0000
3	1,000	4.506	0.1967	5,083	2.261	0.0022
4	2,000	4.506	0.1967	10,167	2.272	0.0070
5	3,200	4.493	0.1956	16,268	2.292	0.0159
6	4,000	4.473	0.1939	20,629	2.297	0.0181
7	5,000	4.415	0.1889	26,469	2.341	0.0376
8	6,000	4.349	0.1833	32,733	2.454	0.0877
9	6,250	4.290	0.1783	35,053	2.499	0.1077
10	6,250	4.230	0.1734	36,043	2.590	0.1480
11	6,320	4.121	0.1646	38,396	2.736	0.2127
12	6,200	3.946	0.1509	41,086	2.972	0.3173
13	6,100	3.847	0.1434	42,538	3.091	0.3701
14	6,050	3.800	0.1399	43,245	3.155	0.3984
15	6,000	3.770	0.1377	43,672	3.194	0.4157
16	5,900	3.689	0.1319	44.730	3.292	0.4592
17	5,800	3.630	0.1277	45,418	3.365	0.4915
18	5,700	3.553	0.1223	46,606	3.444	0.5265
19	5,600	3.499	0.1186	47,217	3.510	0.5558
20	5,500	3.415	0.1130	48,672	3.581	0.5873
21	5,400	3.372	0.1102	49,001	3.649	0.6174
22	5,300	3.303	0.1057	50,141	3.719	0.6484
23	5,200	(Fracture)				

Table 9. Photo-Grid Data for Stress-Strain Relations

Specimen No. 33

Material: 3003-0 Aluminum

Initial Diameter = 0.5010 inch

$K \times 4.530 = 0.5010$

$K = 0.11059$ $K^2 = 0.01223$ $\frac{K^2\pi}{4} = 0.00961$

Frame No.	Load lbs.	Diam. mm.	Area sq.in.	Stress lbs./sq.in.	25 Lines mm.	Strain mm./mm.
1	Identification					
2	0	4,530	0.1972	0	2.267	0.0000
3	500	4.528	0.1970	2,538	2.279	0.0052
4	1,000	4.522	0.1965	5,089	2.290	0.0101
5	1,500	4.519	0.1962	7,645	2.321	0.0238
6	2,000	4.469	0.1919	10,422	2.386	0.0524
7	2,500	4.431	0.1887	13,248	2.510	0.1071
8	2,800	4.315	0.1789	15,651	2.632	0.1610
9	2,900	4.188	0.1685	17,210	2.685	0.1843
10	2,930	4.081	0.1601	18,301	2.833	0.2496
11	2,930	3.987	0.1528	19,175	3.001	0.3325
12	2,900	3.842	0.1419	20,436	3.230	0.4247
13	2,800	3.598	0.1244	22,508	3.585	0.5813
14	2,700	3.433	0.1133	23,830	3.854	0.7000
15	2,600	3.297	0.1045	24,880	4.049	0.7860
16	2,500	3.171	0.0966	25,879	4.222	0.8623
17	2,400	3.052	0.0895	26,815	4.371	0.9280
18	2,300	2.961	0.0843	27,283	4.510	0.9894
19		(Fracture)				

Table 10. Photo-Grid Data for Stress-Strain Relations

Specimen No. 50 Material: 3004-O Aluminum

Initial Diameter = 0.5011 inch

$K \times 4.554 = 0.5011$

$K = 0.11003$ $K^2 = 0.012107$ $\frac{K^2\pi}{4} = 0.00951$

Frame No.	Load lbs.	Diam. mm.	Area sq.in.	Stress lbs./sq.in.	25 Lines mm.	Strain mm./mm
1	Identification					
2	0	4.554	0.1972	0	2.312	0.0000
3	1,000	4.550	0.1969	5,078	2.315	0.0012
4	2,000	4.546	0.1965	10,178	2.318	0.0025
5	3,000	4.517	0.1940	15,463	2.351	0.0168
6	4,000	4.516	0.1939	20,629	2.362	0.0216
7	5,000	4.451	0.1884	26,639	2.421	0.0432
8	5,700	4.366	0.1813	31,439	2.525	0.0921
9	5,830	4.240	0.1710	34.093	2.685	0.1613
10	5,830	4.152	0.1639	35,570	2.780	0.2024
11	5,800	4.067	0.1573	36,872	2.880	0.2456
12	5,700	3.899	0.1446	39,419	3.062	0.3243
13	5,600	3.781	0.1360	41,176	3.198	0.3832
14	5,500	3.702	0.1303	42,210	3.298	0.4264
15	5,400	3.605	0.1236	43,689	3.402	0.4714
16	5,200	3.476	0.1149	45,256	3.559	0.5393
17	5,000	3.350	0.1067	46,860	3.724	0.6107
18	4,800	3.208	0.0979	49,029	3.862	0.6704
19	4,600	3.109	0.0919	50,054	3.995	0.7354
20		(Fracture)				

Table 11. Photo-Grid Data for Stress-Strain Relations

Specimen No. 46 Material: 5052-0 Aluminum

Initial Diameter = 0.5012 inch

$K \times 4.490 = 0.5012$

$K = 0.11162$ $K^2 = 0.012459$ $\frac{K^2 \pi}{4} = 0.009785$

Frame No.	Load lbs.	Diam. mm.	Area sq.in.	Stress lbs./sq.in.	25 Lines mm.	Strain mm./mm
1	Identification					
2	0	4.490	0.1973	0	2.281	0.0000
3	1,000	4.482	0.1966	5,086	2.284	0.0013
4	2,000	4.470	0.1955	10,230	2.289	0.0035
5	3,000	4.445	0.1933	15,519	2.315	0.0149
6	4,000	4.425	0.1916	20,876	2.356	0.0328
7	5,000	4.317	0.1824	27,412	2.437	0.0683
8	5,500	4.253	0.1770	31,073	2.532	0.1100
9	5,700	4.114	0.1656	34,420	2.697	0.1823
10	5,710	3.956	0.1531	37,295	2.910	0.2757
11	5,600	3.767	0.1388	40,345	3.138	0.3757
12	5,500	3.696	0.1337	41,136	3.254	0.4265
13	5,400	3.600	0.1268	42,586	3.338	0.4633
14	5,200	3.447	0.1163	44,711	3.547	0.5550
15	5,000	3.284	0.1055	47,393	3.700	0.6220
16	4,800	3.139	0.0964	49,792	3.864	0.6939
17	4,600	3.008	0.0885	51,977	4.021	0.7628
18	4.400	2.921	0.0835	52,694	4.147	0.8180
19	4,200	2.815	0.0775	54,193	4.260	0.8676
20	4,000	2.740	0.0735	54,421	4,373	0.9171
21	3,900	(Fracture)				

Table 12. Photo-Grid Data for Stress-Strain Relations

Specimen No. 37 Material: 6061-0 Aluminum

Initial Diameter = 0.5008 inch

$K \times 4.508 = 0.5008$

$K = 0.11109$ $K^2 = 0.12341$ $\frac{K^2\pi}{4} = 0.00969$

Frame No.	Load lbs.	Diam. mm.	Area sq.in.	Stress lbs./sq.in.	25 Lines mm.	Strain mm./mm
1	Identification					
2	0	4.508	0.1969	0	2.235	0.0000
3	500	4.504	0.1968	2,540	2.240	0.0022
4	1,000	4.503	0.1965	5.089	2.241	0.0026
5	1,500	4.496	0.1959	7.656	2.239	0.0017
6	2,000	4.470	0.1936	10,330	2.262	0.0120
7	2,500	4.447	0.1916	13,048	2.289	0.0241
8	3,000	4.415	0.1889	15,881	2.322	0.0389
9	3.300	4.331	0.1818	18,151	2.416	0.0809
10	3.410	4.294	0.1787	19,082	2.483	0.1109
11	3.480	4.141	0.1662	20,938	2.671	0.1950
12	3,480	3.967	0.1525	22,819	2.986	0.3360
13	3,400	3.763	0.1372	24,781	3.223	0.4420
14	3,300	3,578	0.1241	26,591	3.437	0.5378
15	3,200	3.435	0.1143	27,996	3.627	0.6228
16	3,100	3.315	0.1065	29,107	3.795	0.6979
17	3,000	3.206	0.0996	30,120	3.930	0.7583
18	2,900	3.078	0.0918	31,590	4.061	0.8170
19	2,800	3.011	0.0878	31,890	4.194	0.8765
20	2,700	2.922	0.0837	32,648	4.277	0.9136
21	2,600	2.827	0.0774	33,591	4.407	0.9718
22	2,500	2.737	0.0726	34,435	4.493	1.0102
23	2,400	(Fracture)				

Table 13. Photo-Grid Data for Stress-Strain Relations

Specimen No. 40 Material: 7075-0 Aluminum

Initial Diameter = 0.5015 inch

$K \times 4.517 = 0.5015$

$K = 0.11102$ $K^2 = 0.012325$ $\frac{K^2\pi}{4} = 0.00968$

Frame No.	Load lbs.	Diam. mm.	Area sq.in.	Stress lbs./sq.in.	25 Lines mm.	Strain mm./mm
1 Identification						
2	0	4.517	0.1975	0	2.248	0.0000
3	1,000	4.512	0.1971	5,073	2.250	0.0008
4	2,000	4.498	0.1958	10,214	2.252	0.0017
5	3,000	4.493	0.1954	15,353	2.270	0.0097
6	4,000	4.479	0.1942	20,598	2.285	0.0164
7	5,000	4.459	0.1924	25,987	2.315	0.0298
8	6,000	4.415	0.1887	31,796	2.357	0.0484
9	6,540	4.348	0.1830	35,737	2.467	0.0974
10	6.620	4.284	0.1777	37,253	2.532	0.1263
11	6,630	4.223	0.1726	38,412	2.600	0.1880
12	6,600	4.058	0.1647	40,072	2.770	0.2322
13	6,550	3.990	0.1541	42,504	2.855	0.2700
14	6,500	3.957	0.1516	42,875	2.923	0.3002
15	6,450	3.916	0.1484	43,463	2.985	0.3278
16	6.400	3.865	0.1446	44,260	3.021	0.3438
17	6,350	3.812	0.1407	45,131	3.058	0.3603
18	6,300	3.788	0.1389	45,356	3.109	0.3830
19	6,200	3.708	0.1331	46,581	3.182	0.4154
20	6,100	3.663	0.1299	46,959	3.262	0.4510
21	6,050	(Fracture)				

Table 14. Photo-Grid Data for Stress-Strain Relations

Specimen No. 2

Initial Diameter = 0.5044 inch Material: Yellow Brass

$K \times 5.862 = 0.5044$

$K = 0.0860$ $K^2 = 0.00740$ $\frac{K^2\pi}{4} = 0.00581$

Frame No.	Load lbs.	Diam. mm.	Area sq.in.	Stress lbs./sq.in	25 Lines mm.	Strain mm./mm
1	Identification					
2	0	5.862	0.1996	0	2.900	0
3	2,000	5.862	0.1996	10,020	2.908	----
4	4,000	5.856	0.1992	20,080	2.916	----
5	6,000	5.850	0.1988	30,181	2.914	0.0048
6	8,000	5.852	0.1989	40.221	2.916	0.0055
7	10,000	5.832	0.1976	50,607	2.935	0.0120
8	12,000	5.848	0.1987	60,393	2.938	0.0131
9	12,750	5.835	0.1978	64,459	2.946	0.0159
10	12,980	5.809	0.1961	66,191	2.977	0.0266
11	13,020	5.765	0.1931	68,358	2.992	0.0317
12	13,080	5.697	0.1886	69,359	3.037	0.0472
13	13,120	5.657	0.1859	70,576	3.096	0.0676
14	13,100	5.508	0.1763	74,305	3.273	0.1286
15	12,900	5.288	0.1625	79,385	3.453	0.1907
16	12,600	5.104	0.1514	83,223	3.687	0.2714
17	12,400	5.004	0.1455	85,223	3.801	0.3107
18	12,200	4.884	0.1386	88,023	3.920	0.3517
19	12,000	4.786	0.1331	90,158	4.009	0.3824
20	11,800	4.712	0.1291	91,402	4.135	0.4259
21	11,600	4.608	0.1234	94,003	4.202	0.4490
22	11,400	4.526	0.1190	95,798	4.414	0.5221
23	11,300	(Fracture)				

Table 15. Photo-Grid Data for Stress-Strain Relations

Specimen No. 25 Material: Monel-R

Initial Diameter 0.5047 inch

$K \times 4.130 = 0.5047$

$K = 0.12220$ $K^2 = 0.014933$ $\frac{K^2\pi}{4} = 0.01172$

Frame No.	Load lbs.	Diam. mm.	Area sq.in.	Stress lbs./sq.in.	25 Lines mm.	Strain mm./mm
1	Identification					
2	0	4.130	0.1999	0	2.091	0.0000
3	4,000	4.132	0.2000	20,000	2.093	0.0009
4	8,000	4.126	0.1995	40,100	2.097	0.0028
5	12,000	4.123	0.1992	60,240	2.095	0.0019
6	16,000	4.117	0.1987	80,523	2.112	0.0100
7	18,310	4.097	0.1967	93,085	2.138	0.0224
8	18,480	4.034	0.1907	96,906	2.303	0.1013
9	18,300	3.953	0.1831	99,945	2.478	0.1850
10	17,600	3.645	0.1557	113,040	2.816	0.3467
11	16,900	3.455	0.1399	114,370	3.027	0.4476
12	16,200	3.299	0.1275	125,490	3.203	0.5318
13	15,500	3.115	0.1137	136,320	3.401	0.6264
14	14,800	3.000	0.1055	140,280	3.530	0.6881
15	14,100	2.924	0.1002	140.720	3.667	0.7537
16	13,400	2.808	0.0924	145.020	3.777	0.8063
17	12,800	2.716	0.0964	148,150	3.906	0.8680
18	12,750	(Fracture)				

Table 16. Photo-Grid Data for Stress-Strain Relations

Specimen No. 27 Material: Inconel

Initial Diameter = 0.5046 inch

$K \times 4.106 = 0.5046$

$K = 0.12289$ $K^2 = 0.015102$ $\frac{K^2\pi}{4} = 0.01186$

Frame No.	Load lbs.	Diam. mm.	Area sq.in.	Stress lbs./sq.in.	25 Lines mm.	Strain mm./mm
1	Identification					
2	0	4.106	0.1999	0	2.115	0.0000
3	4,000	4.105	0.1998	20,020	2.120	0.0023
4	8,000	4.097	0.1991	40,180	2.142	0.0127
5	12,000	3.978	0.1877	63,931	2.264	0.0704
6	15,000	3.954	0.1854	80,906	2.459	0.1626
7	16,700	3.772	0.1687	98,992	2.597	0.2278
8	17,700	3.704	0.1627	108,790	2.750	0.3002
9	18,050	3.492	0.1447	124,740	2.990	0.4137
10	17,5000	3.187	0.1205	145,230	3.391	0.6033
11	16,800	3.127	0.1160	144,830	3.600	0.7021
12	16,400	3.078	0.1124	145,910	3.727	0.7621
13	15,900	2.973	0.1048	151,720	3.824	0.8080
14	15,300	2.923	0.1013	151,040	3.978	0.8808
15	14,700	2.785	0.0920	159,780	4.096	0.9366
16	14,100	2.710	0.0871	161,880	4.224	0.9971
17	13,500	2.632	0.0822	164,230	4.315	1.0401
18	13,000	2.551	0.0772	168,390	4,368	1.0652
19	12,700	(Fracture)				

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